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PLANTING THE SOUTHERN PINES

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VOLUME 2

Nursery Practice

Planting

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CONTENTS, VOLUME II

NURSERY PRACTICE

Large-scale production of southern pine planting stock (fig. 20) is expensive and exacting. Selecting a nursery site requires great care. Sowing, watering, weeding, lifting, culling, grading, packing, and shipping all require close attention to detail. Control of the many troubles from which seedlings suffer requires constant watchfulness, prompt diagnosis, and precise technique. Few if any crops demand more careful soil management or are harder on the soil. The following pages summarize general information on these problems, but for many essential facts the nurseryman must depend on his own library [28/].

28/ In addition to current files of the *American Nurseryman* and the *Journal of Forestry*, the following are suggested for the library of a large, permanent nursery: (a) general texts (Toumey and Korstian, 1942)(___); (b) seed references, including (Baldwin, 1942; Rietz, 1941; U. S. Forest Service, 1948)(___, ___, ___); (c) references on machinery and equipment, like farm implement catalogues and (Smith, H. P., 1948; Turner and Johnson, 1948)(___, ___); (d) references on insects and diseases, including (American Assoc. Ec. Ent., 1949; Craighead, 1950; Davis, Wright, and Hartley, 1942)(___, ___, ___); (e) soils references, including (Lutz and Chandler, 1946; U. S. Dept. Agr., 1938; Wilde, 1946)(___, ___, ___); (f) texts on fertilizers, like (Andrews, 1947)(___); and (g) texts on statistics, like (Snedecor, 1946)(___), and on sampling (Schumacher and Chapman, 1948)(___); and (h) the latest bulletins and circulars of the U. S. Department of Agriculture and State experiment stations on cultural practices, soils, fertilizers, composts, green-manure crops, insects, and disease.

Figure 20.--A permanent State nursery producing 20 million or more southern pine seedlings per year.

The requirements for buildings and equipment vary so much from nursery to nursery, and both agricultural and special nursery equipment are being improved so rapidly, that it is impracticable to describe them in detail. The minimum requirements include tractors, trucks, plows, harrows, and hand tools; a bed shaper, a pine seeder, and bed-cover layers and removers; often a separate seeder for soiling crops; perhaps a manure spreader; always an overhead sprinkler system and a power sprayer, seedling lifters and balers, and frequently a conveyer-belt grading table; often a seed extractory and cold storage plant; usually residences, equipment sheds, and an office; and always a good fence. The county agricultural agent can usually suggest power requirements and type of plows and harrows for local soils. Up-to-date specifications for special appliances may be obtained from the Regional Forester, U. S. Forest Service, Atlanta, Georgia 29/ .

29/ The following references, in addition to implement catalogues and various State agricultural experiment station publications, contain useful information about equipment: (Allen, Richard C., 1942; Brener, 1939; Cossitt, 1938; Hamner and Tukey, 1947; Hartman, 1948; Huberman, 1935; Ilgenfritz, 1948; Lewis and Eliason, 1937; McComb and Steavenson, 1936; McKeithen, 1937; Otis, 1947; Reed, 1948; Robbins, 1942; Story, 1940; Toumey and Korstian, 1942; Turner and Johnson, 1948; Umland, 1946)(___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___).

NURSERY SITE AND LAYOUT

No step in artificial reforestation requires more care than does selecting the site for a permanent nursery. Good nursery sites are likely to be superior, high-priced farm land. Experience has shown, however, that buying a good site may cost far less than correcting unsuitable conditions on a poor one.

Location

A central location within the territory served by the nursery minimizes stock-shipping costs. If the territory is large, however, a location well north of its center may be necessary to keep seedlings from resuming height growth in the beds before the planting season is over at its northern edge.

Access to water, main highways, labor, express and freight facilities, telephone, electric power, and cold storage, as well as to medical, school, and similar facilities for the nursery staff, is important.

Localities of serious insect and disease hazard, including sites infested with harmful soil fungi or nematodes, should be avoided. Determination of soil insect, fungus, or nematode infestation usually requires not only field examination but also laboratory and greenhouse culturing (Wright, 1945)(___) and a thorough study of the past history of the site; the State agricultural experiment station may be the logical agency to do the culturing. The existence of quarantine lines that will prevent shipment of stock should be checked with both the U. S. Bureau of Entomology and Plant Quarantine and the State plant board (p. 536) before the nursery is established.

Capacity

To insure against unforeseen losses, the total area of seedbeds and paths allowed for a given number of seedlings should be about 20 percent greater than the net area required (table 17) at the desired seedling stand density. This total must, in turn, be doubled if soil-improving crops are to be alternated annually with seedlings.

Space must be allowed for roads and buildings, and for increases in the seedbed area if the planting program expands. Control of a few acres of fairly severe planting site adjacent to the nursery aids greatly in field testing debatable nursery treatments.

Table 17.--Areas [1] required for 1,000,000 seedlings at different combinations of bed and path width and seedling stand density

Seedlings per square foot	3-foot beds: 2-foot paths	3-foot beds: 1½-foot paths	4-foot beds: 2-foot paths	4-foot beds: 1½-foot paths	5-foot beds: 2-foot paths	5-foot beds: 1½-foot paths
	Acres					
20	1.91	1.72	1.72	1.58	1.61	1.49
25	1.53	1.38	1.38	1.26	1.29	1.19
[2] 30	1.28	1.15	1.15	1.05	1.07	.99
35	1.09	.98	.98	.90	.92	.85
40	.96	.86	.86	.79	.80	.75
45	.85	.77	.77	.70	.71	.66
50	.77	.69	.69	.63	.64	.60

1/ Including beds and the paths separating them, but not roads, cross-paths, or width added to paths along sprinkler lines.
2/ Practicable average density on most nursery soils.

Water

A prime need is a dependable water supply, large enough to lay down the equivalent of 4 or 5 inches of rainfall a month over the entire area likely to be used for pine seedlings in any one year. The rate of flow must be sufficient to apply ½ inch over the entire seedbed area in 12 hours or less. Five inches of water on one acre--ordinarily the minimum area to produce a million seedlings--requires 136,000 gallons. Residences, shops, and the fire protection system require additional amounts.

Water carrying 500 parts of calcium per million is dangerously likely to raise the pH concentration of nursery soil and to increase damping-off, root rot, and chlorosis; water carrying 100 parts of $CaCO_3$ or 125 parts of calcium bicarbonate per million may do so (Auten, 1939; Chapman, 1941; Davis, Wright, and Hartley, 1942; Davis, Young, Latham, and Hartley, 1938)(___, ___, ___, ___). Usually, however, water from streams running wholly within the southern pine types is safe so far as calcium is concerned. Water with a high silt or colloidal content may seal the soil surface, reduce soil aeration, and predispose seedlings to disease, and the water itself may carry disease organisms (Davis, Wright, and Hartley, 1942)(___). Sediment or algae in the water may clog sprinkler nozzles. No nursery should

be established until analysis by the State agricultural experiment station or other qualified agency has shown that the available water is free from, or can readily be freed from, all such harmful substances and organisms. It is well also to test the water throughout a full growing season in advance of nursery establishment, both to see whether regular applications increase the pH concentration of the top $\frac{1}{4}$ to $\frac{1}{2}$ inch of soil over that of soil 3 inches down and of top soil in unwatered plots (Davis, Wright, and Hartley, 1942)(___), and to learn their effect on seedlings in plots or pots.

Topography and Soil

Sites with excessive surface drainage and erosion should be avoided. Ordinarily the slope of the seedbed area should nowhere exceed 2 or 3 percent, yet the site must not be absolutely flat lest water stand after rain. Subsurface is as important as surface drainage; "crawfish" land is unsuitable for pine nurseries. Land subject to overflow is useless.

The soil should be uniform in depth and texture as well as in slope. The best nursery soils are fine to coarse sandy loams, underlain at 18 inches or slightly more by somewhat stiffer but still permeable subsoils. A stiff subsoil less than 12 inches below the surface is very undesirable.

Soils containing not less than 15 nor more than 25 percent by weight of particles smaller than 0.05 mm. in diameter are recommended. Such particles generally remain suspended in water after the soil has been mixed with water (shaken hard 60 times in a partly filled flask) and allowed to stand for 60 seconds, while larger particles settle out within that time (Wilde, 1935)(___); more accurate special techniques and apparatus are also available for these measurements (Wilde, 1946)(___). The lighter soils are better drained and easier to work and (Howell, 1932; Lenhart, 1934; Veihmeyer and Hendrickson, 1948)(___, ___, ___) permit better seedling root development than heavy soils. Extremely light, loose, sandy soils, low in organic matter and with poor moisture-retaining capacity--wilting coefficient less than 4 percent(Davis, Wright, and Hartley, 1942)(___)--should, however, be avoided, as should those that are easily eroded by wind or water, that puddle, cake, or crust after wetting, or that contain much stone or gravel.

The pH concentration of the soil should not be above 6.5, lest the seedlings suffer from damping-off, root rot, and chlorosis; nor below 4.5, lest mineral nutrients be rendered unavailable to the seedlings (Anonymous, 1936; Davis, Wright, and Hartley, 1942; Hartley, 1935; Wilde, 1934; Wilde, 1946)(___, ___, ___, ___, ___).

The mineral nutrient level of nursery soils should be at least as high as that required by agricultural crops grown on former pine land, and should be capable of easy maintenance and improvement. The great weight of plant tissue per acre produced by southern pine seedlings when grown at ordinary seedbed densities, together with its practically complete removal during lifting, makes the annual drain of pine seedling crops upon soil nutrient material several fold (unpublished data) that of cotton or corn.

It is thought that the organic content of nursery top soil should not be below 1.5 percent, preferably not below 2.5 percent.

The presence of abundant mycorrhiza-forming fungi (p. 235) in the soil appears desirable, but can ordinarily be counted on anywhere within the southern pine types.

Other things being equal, weedy areas should be avoided, especially those infested with Johnson grass, Bermuda grass, or worst of all, nutgrass (coco grass). Luxurious weed growth, however, usually indicates high soil fertility, and meager weed growth, low fertility.

The soil is the hardest thing about a nursery site to evaluate. The only reasonably dependable way is to grow several small trial beds of seedlings for one and preferably for two years before the site is developed (Davis, Wright, and Hartley, 1942; Hartley, 1935)(___, ___). At least one such test crop should be outplanted on average to fairly severe sites to see how the seedlings survive the first year.

Nursery Layout

Utmost care should be taken to lay out beds correctly when the nursery is established. Changes made later to improve drainage, control erosion, or reduce operating costs may necessitate placing beds on or across former paths where the soil has become so firmly packed that several years of subsequent cultivation and fertilization will fail to restore full productivity.

A combination of 4-foot-wide beds and 2-foot paths is the general rule. Most standard machinery is well adapted to this combination and most special machinery has been designed to fit it. Paths in which sprinkler lines run must be at least 4 feet wide to allow machinery to clear the sprinklers. Beds 5 feet wide reduce the cost of sowing by hand with transverse drill seeders where these are used instead of mechanical seeders, and, like a few other odd bed and path widths (table 17), are still preferred in occasional small nurseries.

The longer the beds, the more efficiently they can be made, sown, sprayed, and lifted by machinery. The maximum length depends on the length of overhead sprinkler line that an oscillator can turn. This is usually 400 to 500 feet if the water mains cross the ends of the beds and 800 to 1,000 feet if the mains cross the middle of the beds and pairs of oscillators are used.

The surface and subsurface drainage, erodibility of the soil, and economy of sprinkler-line construction usually determine the direction of the beds. On sites with both poor subsurface and poor surface drainage, the beds should run up and down whatever slope there is. On sloping ground, where surface drainage is ample and there is some tendency toward erosion, beds should be straight and should parallel the contours as nearly as possible. (Only in extreme cases should the beds be curved to follow the contours.) On a nearly level site with good subsoil drainage and no erosion, the beds may be run in whatever direction requires the least amount of pipe for sprinkler lines. Where drainage and other conditions permit, it may pay to run beds and sprinkler lines at right angles to the winds prevailing during germination or during the driest weeks of the summer. Such an arrangement insures optimum distribution of water from the sprinklers and minimum water loss from the beds.

Overhead sprinkler lines ordinarily are set 50 to 56 feet apart. The U. S. Forest Service places sprinkler lines 56 feet apart, with nine 4-foot beds and eight 2-foot paths between each two lines, and a 4-foot path under each line. This arrangement permits the most efficient spraying of the beds with a spray rig equipped with the standard 3-bed (15- or 16-foot) boom.

Nursery roads and road ditches and other drainageways should be laid out at the start to carry the maximum traffic and water anticipated. Roads should be at least 16 and preferably 24 feet from shoulder to shoulder. They should be gravelled for all-weather service and to keep down weeds. It is usually sufficient to break nurseries into approximately 10-acre (10-million seedling) compartments by interior roads that cross one another at right angles, with each compartment containing twenty 400-foot sprinkler lines spaced 56 feet apart.

In many nurseries, terraces are essential to erosion control. They must be expertly placed and built, and well maintained, or they may do more harm than good. Sprinkler lines and straight beds should parallel terraces as closely as possible. Some effective seedling area usually is lost where beds cross terraces, although the terraces seldom need hamper machine sowing, spraying, or lifting.

So far as slope, drainageways, and terraces permit, it pays to keep beds uniform in size. Beds of exactly equal area greatly simplify fertilizing, sowing, spraying, and machine operation generally, and particularly nursery inventory and cost accounting.

SOWING

Because of the exacting requirements of southern pine seed for germination (p. 181) and of seedlings for development (p. 286), it is essential to: (a) choose the right sowing date for each species; (b) determine the correct sowing rate for each seed lot; (c) pulverize the soil thoroughly; (d) sow the seed on the surface; (e) roll soil and seed after sowing; and (f) cover the seed until germination is almost complete. Thorough watering of the beds immediately after sowing and during germination is also necessary, but is merely the beginning of a process continued till fall.

Season of Sowing

In the Lower South, most sowing is in February or March; some slash pine is sown in April. Farther north, because of the late spring, southern pine beds are sown in March or April, some even in early May.

The principal exception to spring sowing is with longleaf pine, the greater part of which, since about 1939, has been sown in November and early December. January and late December are likely to be too cold even for longleaf pine. In the northerly nurseries, loblolly and shortleaf seed is also sometimes sown in the late fall, without pregermination treatment, before the ground freezes but after the temperature has become too low for germination. The over-winter contact with the moist soil takes the place of stratification, and when the soil warms in the spring the seed usually germinates promptly and uniformly and gives the seedlings the longest possible growing season.

Spring-sown longleaf beds should ordinarily be put in before those of any other species. Longleaf seed not only germinates better at low temperatures than seed of other species, but is least likely to germinate well at high temperatures (p. 183). Furthermore, longleaf seedlings require a long growing season to attain plantable size, and late-sown longleaf is particularly subject to damping-off.

Shortleaf must usually be sown earlier than loblolly, because the seedlings take longer to reach plantable size. In the more southerly nurseries the growth of shortleaf seedlings practically ceases during the hottest summer weather, and early sowing is necessary to make them as large and as heat resistant as possible before this check occurs.

Because of its usually prompt germination, rapid growth, and early attainment of heat resistance, slash pine may be sown the latest of the four principal southern pines. Fall sowing of slash

is undesirable because it may result in premature germination of some seed during the winter, and is always likely to produce excessively large stock.

Low nursery soil fertility may require early sowing to produce seedlings of plantable size by lifting time. High soil fertility may require late sowing to prevent excessive growth; sowing of slash pine in particular is sometimes deferred until April for this reason.

Late spring sowing may decrease injury from freezing and frost heaving, the extent of bird-damage and the cost of patrolling against birds, and the cost of weeding. It may reduce fusiform rust infection on slash and loblolly nursery stock, and it certainly reduces the amount of spraying necessary to control this rust. On the other hand, late sowing is likely to increase damping-off, heat and drought injury, and injury by Sclerotium bataticola (pp. 248 and 255).

Preparation of Ground and Seedbeds

In large nurseries much or all bed-making and finishing is done with regular agricultural machinery and special bed-shaping equipment, both tractor-drawn. Hand work is limited to odd corners, to places where beds cross terraces, and to occasional final smoothing or freshening of the bed surface.

The beds must be worked when the soil is neither too dry nor too wet, especially the latter. If too dry, it is hard to break up clods or reach the proper depth. If too wet, puddling and clodding may result, with consequent injury to the crop and increase in the cost of later cultivation and weeding.

Plowing must be deep, at least 8 or 9 inches, to permit good development of seedling roots. Harrowing must be deep and thorough for the same reason, and to provide good germinating conditions for the seed. The most suitable implements depend largely on the soil, and usually can be determined by noting which types work best on similar soils nearby.

Beds must be free from any coarse organic material likely to make the surfaces uneven or to prevent good establishment of seedlings. Even light winter cover crops must be turned under 4 to 6 weeks before final bed preparation; heavy crops, considerably earlier. Only well decomposed or finely divided compost or other organic matter may be applied safely just before the beds are made up.

Light crops of annual weeds should be destroyed by plowing or harrowing a little in advance of bed-making. Heavy or carry-over weed crops may require repeated working during a considerable period in advance of sowing. Bermuda and Johnson grass may require special

harrowing before bed-making. Only disk harrows should be used on nutgrass; toothed harrows spread it and make ultimate control more difficult.

Heavy soils, heavy subsoils with poor subsoil drainage, and very level sites with poor surface drainage all call for beds rather high above the nursery paths. Usual elevations are 3 or 4 inches, but in extreme cases beds are built up 6 inches or more above the paths. On soils that erode easily, or on very sandy or otherwise dry sites, beds should be kept low. Local observation and experience are the best guides to the optimum elevation, which may differ from place to place in the nursery.

Theoretically, the surface of the bed should be flat on ideal soils, slightly rounded on the less well drained soils, and slightly troughed on droughty soils (Toumey and Korstian, 1942)(___). Rounded beds, however, have shown little practical superiority (Davis, Wright, and Hartley, 1942)(___), and in most southern pine nurseries bed surfaces are made flat, regardless of soil.

Curbs of low-grade lumber, nailed to stakes in the ground, were formerly used in most nurseries to keep the edges of the beds from crumbling or washing. Today almost universal practice is to add an unsown shoulder on each side of the bed; 3-inch shoulders are wide enough on most soils, but 6-inch may be needed where beds are high above the path and the soil erodes easily. Since the shoulders are on the same level as the beds, they offer no obstruction to mechanical seeders. As the season advances, the unsown shoulders gradually wash or are trampled down into the paths, until by lifting time the beds are reduced almost exactly to 4 feet and the paths widened to full 2 feet--assuming the nursery uses 4-foot beds on 6-foot centers.

In very small nurseries, beds are shaped by hand. In large nurseries, they are shaped by attachments to farm tractors, or by special bed-shapers (Cossitt, 1938; McKeithen, 1937; Story, 1940; Toumey and Korstian, 1942)(___, ___, ___, ___). The best of these devices space beds accurately with no guides except stakes at each end.

Hand-shaped beds are sometimes settled by allowing them to be rained on a few times and then releveling and freshening the surface just before sowing. On most soils it is quicker and equally effective to roll the beds before or after sowing, or both, with 300- to 400-pound metal or wooden rollers, preferably 4 or 5 feet in diameter. Where tractor-drawn bed-shapers and mechanical seeders are used, the weight of the bed-shaper partly settles the beds and the rollers in the mechanical seeder complete the process. With such equipment settling by rain or special rolling is unnecessary.

Final pulverizing of the seedbed surface can be done either by the mechanical bed-shaper or with hand rakes. Surfaces that have dried in the sun or become crusted by rain are freshened by dragging or by hand-raking, immediately before sowing, to permit rolling the seed into at least moderately moist soil.

Most southern pine seedbeds are machine-sown, either in drills running lengthwise of the beds, or broadcast. Drills are essential if, during the growing season, the seedlings are to be side-dressed with dry fertilizer, or cultivated. Some nurserymen feel that, on stiff soils, seedlings in drills can be lifted with less root-injury than those in broadcast beds. With present-day equipment and techniques, however, especially mineral spirits weeding (p. 226), broadcast beds cost no more than drill-sown beds to sow or weed, and seem likely to replace the latter in many nurseries. Broadcast sowing reduces some diseases, particularly sand-splash damping-off of longleaf pine (p. 249), and theoretically permits better development of the seedlings than does drill sowing.

Method of Sowing

Lengthwise drills usually are sown 6 inches center to center. On a 4-foot bed, this arrangement permits eight drills between the two protective shoulders. To allow greater space for cultivation and side fertilization, some nurserymen sow only seven or six drills on a 4-foot bed, but increase the number of seedlings per foot of drill. Six drills is about the minimum without seriously overcrowding the seedlings in each drill or reducing the number of seedlings per bed.

To leave maximum clearance for cultivator and fertilizer attachments, loblolly, slash, and shortleaf seed usually are sown in as narrow a drill as possible. Longleaf seed, however, should be sown in a band 1 to $1\frac{1}{2}$ inches wide, to reduce sand splash.

The commonest device for sowing drills lengthwise of the bed is the Hazard seeder (Toumey and Korstian, 1942)(___). This consists of tractor-drawn rollers carrying eight modified grain-seeding tubes fed from a common seed hopper. The best model permits simultaneous adjustment of the streams of seed flowing through all 8 tubes. Widths of drills or bands sown can be adjusted by raising or lowering the tubes or changing the shape of their outlets. For longleaf seed, the persistent wing stubs of which prevent free passage through ordinary tubes, the Williamson attachment, consisting of a wide-throated, sprocket-driven auger bit in each tube, is necessary (Cossitt, 1938; Huberman, 1935)(___, ___). Specifications, including those for an attachment which utilizes the roller of the seeder to lay cloth seedbed cover over the seed, can be obtained from the Regional Forester, U. S. Forest Service, Atlanta, Georgia. For other means of sowing drills lengthwise, see (McComb and Steavenson, 1936)(___) and (Toumey and Korstian, 1942)(___).

Seed is sown broadcast with the Hazard seeder simply by raising the outlets of the tubes well above the surface of the bed, or by incorporating a "splatterboard" beneath the openings.

Hand sowing, either in drills running crosswise of the bed, or broadcast, remains preferable to machine sowing in very small nurseries and in certain test plots in large ones. Crosswise drills, usually sown 6 inches apart, are easier to hand-weed, especially in 5-foot beds, than drills running lengthwise.

The Bateman [30] seeding trough, which is opened to drop seed, closed again, and moved along the bed by tall handles (fig. 21), is perhaps the most efficient device for sowing crosswise drills by hand. Two men scattering seed in their respective halves of this trough with suitable measures cut from shotgun shells or (for longleaf) baking powder tins, can drill-sow about 100 linear feet of either 4-foot or 5-foot-wide bed per hour. Troughs and drills 4 feet long are used for test plots in standard 4-foot beds, but 5-foot troughs, drills, and beds are more economical where the whole nursery is hand-sown. (Toumey and Korstian, 1942; Wakeley, 1935)(___, ___).

30/ The late F. O. Bateman, while Chief Ranger of the Great Southern Lumber Company at Bogalusa, Louisiana, defined many principles and devised many tools and techniques still applicable wherever the southern pines are planted (Wakeley, 1941)(___).

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Figure 21.--Bateman seeding trough for sowing drills crosswise of the nursery bed. Pushing the handles together opens the bottom of the trough and drops the seed. Six-inch wooden guides projecting from the far side space drills correctly.

Uniform hand broadcasting of seed is time-consuming and requires considerable care. Each bed and the seed for it must be systematically subdivided into equal parts, each subdivision of the seedbed sown with about three-fourths of the seed allotted to it, and the thinly sown portions touched up with the remaining one-fourth.

Density of Seedling Stand

The optimum average number of living southern pine seedlings per square foot throughout the growing season and on to lifting time usually varies from about 30 to 45, depending on species and on soil

fertility. Sowing in drills instead of broadcast does not reduce the optimum number unless the drills are spaced more than 8 inches apart.

Longleaf seedlings, because they are largest, should be grown at the lowest density, and slash at not much higher densities. Loblolly and shortleaf seedlings can be grown at higher densities than slash; the maximum is about 50 to 55 per square foot. The 70 per square foot formerly recommended for shortleaf (Wakeley, 1935)(___) is excessive; Chapman (Chapman, A. G., 1948)(___) recommends a maximum of only 25 per square foot for shortleaf in Central States nurseries. At densities below 30 per square foot, slash and longleaf pine seedlings may not fully utilize the capacity of the soil; densities above 30 may decrease the size of the seedlings appreciably; increasing the soil fertility may increase the number of seedlings of a given size that can be grown per square foot (Muntz, 1944)(___). In general, a unit area of a given nursery soil tends to produce a constant weight of seedling tissue in the form of either many small or fewer large seedlings (Soc. Amer. For. N. Y. Sec., Com. Tech. Prac., 1932)(___). The exact number of living seedlings per square foot that is most suitable for each nursery must be determined by local experience and tests.

The emphasis on <u>living</u> rather than on plantable seedlings per square foot is important. All living seedlings, even if unplantable because of infestation, infection, or small size, compete with and therefore affect the development of neighboring seedlings. Under favorable nursery conditions, 80 percent or more of all living seedlings are plantable. In nurseries where the number plantable consistently falls far below the number of living seedlings, the desired quota of planting stock can be met only by sowing additional beds. Sowing more seed per bed merely intensifies competition among seedlings and may make them all unplantable.

Sowing Rate

Seedling stand density depends first and foremost upon the rate at which the seed is sown. Sowing at the correct rate assures almost exactly the desired number of living seedlings per square foot at lifting time unless catastrophic injuries occur. The sowing rate can be calculated in terms either of the weight of seed to be sown per bed, or of the number of full seeds to be sown per running foot of drill.

Rates calculated by weight can be applied directly only to seed sown at about the moisture content at which the number of seeds per pound was determined; they cannot be used with seed moistened by stratification unless the seed has been stratified in small, separate lots, the dry weights of which are known (p. 161). Calculation of rates by weight requires determination of number of seed per pound,

purity percent, and effective germination percent, but has the great practical advantage of not requiring cutting tests of seeds ungerminated at the end of the germination test.

Rates calculated by numbers of full seeds are applicable directly both to dry and to stratified or soaked seed, including lots from which some empty seeds have been removed with the stratifying medium. They do not involve purity percents or numbers of seeds per pound. They do, however, require determination of effective germination percents in terms of seeds with full kernels, instead of in terms of all seeds tested, and therefore necessitate cutting tests both at the end of the germination test and when adjusting the seeder.

Only part of the seeds found effectively germinable by test can be depended upon, even in the absence of epidemics and catastrophes, to produce seedlings at lifting time. Drought, heat, soil wash, weeding, non-epidemic insects, and the like inevitably cause small to moderate annual losses rather uniformly distributed throughout the beds. Any sowing rate formula must therefore include the percentage of effectively germinating seeds expected to survive until fall. In U. S. Forest Service nurseries this percentage has usually been 80 to 95, in some cases 65, and in a few instances as low as 25. In any nursery the most likely percentage must be estimated for each sowing lot, preferably in the light of past experience and records. Where previous observations are lacking, the nurseryman should assume a percentage somewhere between 90 and 70. Good overwinter storage conditions, rapid and high germination in the laboratory, favorable sowing conditions, good soil, and small likelihood of insects and diseases suggest using the higher figure. The reverse, and particularly a low germination percent (Baldwin, 1942; Read, 1940)(___, ___), make 70 a safer estimate.

<u>Sowing by weight</u>

$$\text{Weight} = \frac{(\text{Area of bed})(\text{Seedlings desired per square foot})}{(\text{Seeds per pound})(\text{Purity \%})(\text{Germination \%})(\text{Expected survival \%})}$$

In this formula:

<u>Weight</u> is the pounds of dry, commercially cleaned seed to be sown per bed.

<u>Area of bed</u> is in square feet.

<u>Seedlings</u> means average number of all living seedlings, plantable and unplantable, that the nurseryman wishes to have per square foot at lifting time.

<u>Seeds per pound</u> means average number of pure seeds determined by test or approximated from tables (p. 501).

Purity percent is that of the sowing lot, determined by test (p. 176) after final cleaning.

Germination percent is effective germination percent (p. 190), determined by test (p. 181), and based on all seeds tested.

Expected survival percent is the average percentage of the effectively germinable seeds expected to survive as seedlings at lifting time. This percentage is estimated by the nurseryman as already noted.

In applying the formula, the three percentages are expressed as decimals. As an example, how many pounds of longleaf pine seed must be sown in a 4- by 400-foot bed (1,600 square feet) to get 30 seedlings per square foot, if there are 4,200 seeds per pound, purity percent is 92, effective germination percent is 68, and 73 percent of all effectively germinable seeds are expected to survive as trees at lifting time? Carrying the calculation to three significant figures:

$$\text{Weight} = \frac{1{,}600 \times 30}{4{,}200 \times .92 \times .68 \times .73} = \frac{48{,}000}{1{,}920} = 25.0 \text{ pounds}$$

Similar procedure may be used to calculate the weight of seed required for a given length of drill, substituting drill length, in feet, for bed area, and number of living seedlings desired per linear foot of drill for number per square foot. In calculating how much seed to sow by hand in drills crosswise of the bed, grams are more convenient than pounds.

Sowing by number

$$\text{Full seeds to sow} = \frac{\text{Seedlings desired per linear foot of drill}}{(\text{Germination \%, based on full seeds})(\text{Expected survival \%})}$$

In this formula:

Full seeds to sow means average number of seeds with kernels, per linear foot of drill. The attainment of this number must be verified by cutting or hammer test (p. 175) while adjusting the seeder.

Seedlings means average number of all living seedlings, plantable and unplantable, that are desired per linear foot of drill at lifting time.

Germination percent based on full seeds is effective germination (p. 190), determined by test (p. 181) and based on all seeds with kernels as shown by cutting seeds remaining ungerminated at the end of the test (p. 175).

Expected survival percent is the same as in the preceding formula.

In applying the formula, the two percentages are expressed as decimals. As an example, how many seeds with kernels must be sown per running foot of drill to get 18 living seedlings per foot, at lifting time, from a lot of slash pine seed in which 90 percent of all seeds with kernels germinate effectively, in a nursery in which 80 percent of the effectively germinable seeds may be expected to survive as trees at lifting time?

$$\text{Full seeds to sow} = \frac{18}{.90 \times .80} = \frac{18}{.72} = 25 \text{ full seeds per linear foot.}$$

For machine drill sowing, the seeder is adjusted during successive trial runs over a tarpaulin until all tubes combined drop the correct weight of seed within a convenient measured distance, or until each tube drops the correct number of full seeds per foot of individual drill. For machine broadcasting, the seeder is adjusted as though the desired average number of seedlings per square foot were to be grown in drills; then the seeding tubes are raised or a splatter-board put on to distribute the seed uniformly over the entire width of the bed.

Catastrophic losses, particularly those caused by freezing, hail, flooding, mass inroads of birds and rodents, and epidemics of insects and disease, usually occur in concentrated areas instead of uniformly throughout the beds. Increasing the rate of sowing cannot reduce and, with certain diseases, may increase the losses within such concentrated areas, and results in overdense stands everywhere else. Therefore, as in the case of low percentages of plantable seedlings (p. 215), the only way to keep nursery production up to quota despite catastrophic injuries is to sow extra beds at the regularly calculated rate. With southern pines, the U. S. Forest Service increases the number of beds by 20 percent for this purpose.

Mixing Seed Before Sowing

Just before the seed is sown, it must be thoroughly mixed. If it is not, inevitable variations in germinability in different parts of the sowing lot may nullify all the care taken in sampling and testing the seed, calculating the sowing rate, and adjusting the seeder. In a number of cases, despite correct average rates of sowing, failure to mix seed has resulted in nearly twice the desired stand in some beds and practically no seedlings in others, with consequent injuries to stock and increases in costs.

Mixing must be done immediately before sowing. If the seed is stored very long or transported far, especially in several separate containers, between mixing and sowing, serious differences in germinability are likely to develop within and among containers and to cause corresponding variations in the density of the seedling stand.

A sowing lot that has been kept in a single container may be mixed by pouring it out on a tarpaulin or a smooth floor and turning it over several times with a shovel. Lots large enough to require more than one container are most easily mixed by spreading the seed from successive containers in thin layers one on top of another and then thoroughly mixing the layers with shovels. To avoid crushing seeds, the men doing the mixing should work without shoes.

Such mixing is an economy. The labor involved does not add measurably to the cost per thousand trees produced. The uniform stands that result from mixing not only improve the quality and uniformity of the seedlings, but also greatly reduce the cost of nursery inventories by reducing the number of samples needed for a given degree of accuracy (p. 262).

Seedbed Covers

Beds must be covered to protect seed from birds and from displacement by rain, and particularly to keep seed and soil continuously moist. The last is so even with overhead sprinklers to supply water. The covering must let water and presumably some light reach the seed. It must be non-toxic, inexpensive, quick and easy to apply and, if need be, easy to remove. A cover which does not meet these specifications may seriously reduce or completely destroy the seedling stand.

Most nurserymen cover southern pine seedbeds with cloth or with pine needles--commonly called pine straw. Both cloth and pine straw have proved superior to grain straw, paper, sawdust, soil, and sand.

Cloth covers can be laid and removed more quickly than pine straw. During germination they give better protection against birds and flooding rains. Their chief disadvantages are high initial cost of cloth and pins, the necessity of timing their removal exactly, the tendency of certain soils to pack hard under cloth, deterioration of the cloth, and vulnerability of the seedlings to hail and to heavy rain during the first two or three weeks after the cloth is removed.

Pine straw usually requires more labor than cloth does to apply and remove, gives less protection against birds, floats away if rain floods the beds, and (Davis, Wright, and Hartley, 1942)(___) is a potential source of needle infection. Pine straw, however, requires no wire pins, prevents rain-packing of the soil, and at most nurseries can be obtained in quantity at short notice. Seedlings of all southern pines except longleaf easily come up through a properly applied layer of pine straw. If too thin or too thick a layer of pine straw is applied, the thickness can be adjusted even while germination is taking place. Even longleaf seedlings are less seriously

flattened and less rapidly smothered by pine straw than by cloth. Therefore removal of pine straw need not be timed as precisely as the removal of cloth; this is especially advantageous with seed that germinates slowly and irregularly. In nurseries subject to excessive heat, drought, or wind-erosion, part of the straw may be left in place all summer as a mulch; in some nurseries this practice has materially improved the quality of the nursery stock.

The two favorite cloth covers are jute burlap and Osnaburg or similar rather porous cotton cloth. Burlap weighing 9 or 10 ounces per square yard is preferred; 12-ounce burlap is a little too thick and unnecessarily expensive, while 7- or 8-ounce burlap is a trifle light, especially after a season's use. The U. S. Forest Service specifies 9-ounce burlap with 11 to 13 threads per inch of warp and 10 to 12 per inch of filling. New burlap may be purchased in 100-yard rolls, in any desired width; 54-inch width is preferred for 4-foot beds. Second-hand bags may be bought already stitched together in strips, at less cost, but have the disadvantages of variations in weight and durability, seams that hinder laying and disturb the seed when the cover is removed, and, frequently, holes that expose the seed.

Although cloth covers may be laid by hand or by mechanical layers pulled behind the seeder, the best way is by a reel mounted on top of the seeder. This device allows the cloth to pass under the roller of the seeder and to be pressed into place on top of the seed. It permits sowing even when the beds are so moist that, without the intervening cloth, soil and seed would stick to the roller.

The cloth is stretched tight and fastened down with pins stuck through the edges and into the ground--most efficiently by two men riding a low trailer drawn behind the burlap layer or seeder. The pins are usually 15-inch lengths of No. 8 uninsulated telephone or slightly heavier galvanized wire, bent to a ring at one end. Placed at 3-foot intervals to keep the wind from flapping the cloth and injuring the seedlings, such pins for a 4- by 400-foot bed require about 350 feet of wire. Pins for an acre of 4-foot beds with 2-foot paths require about 6,000 feet of wire.

Cloth covers must be removed before an appreciable percentage of the first seedlings have been smothered or have worked their way through the fabric, but not until most of the seed has germinated. (These requirements place a premium on uniformly rapid germination of the seed, and are one of the principal reasons for pregermination treatment.) A rough practical rule is to take off cloth covers when seedbed germination equals two-thirds to three-fourths of laboratory germination--usually from 10 to 35 days after sowing, but in extreme cases as few as 6 or as many as 60 days. Great care in as well as correct timing of removal is necessary to avoid destruction of seedlings just taking root (p. 231).

For storage after use, cloth must be cleaned by washing (laying it on the grass in the rain is common practice) or beating, and must be thoroughly dried. Failure to clean and store untreated cloth covers properly may necessitate buying a complete new supply each year. Recently developed treatments with copper naphthenate alone (Anderson and Kinneer, 1949)(___) or copper naphthenate and chrome green promise to prolong the life of burlap bed covers greatly. Details of the latter treatment, including precautions to avoid injury to seed, may be obtained from the Regional Forester, U. S. Forest Service, Atlanta, Georgia. Treatment at the nursery costs about 5 cents a lineal yard.

Pine straw is scattered evenly over the beds by hand or with forks, or with a manure spreader modified to prevent sidewise scattering. The correct depth is $\frac{1}{2}$- to 1 inch deep before settling and less than $\frac{1}{2}$ inch after settling--just enough to conceal the seed from sight. The pine straw required for a 4- by 400-foot bed totals between $2\frac{1}{2}$ and 5 cubic yards. An acre of 4-foot beds with 2-foot paths requires 45 to 90 cubic yards of straw. Loblolly straw is most satisfactory; slash is next. Shortleaf pine straw is rather fine and longleaf somewhat coarse for best results. The fewer twigs and cones the pine straw contains, the easier it is to spread. Storing the straw in piles for a year before use rots it somewhat and facilitates uniform distribution with a manure spreader.

WATERING, WEEDING, AND RELATED CARE

Watering

Southern pine seedbeds generally need about an inch of water a week--perhaps slightly more on light and slightly less on heavy soils--from the time they are sown until late August or early September. In most southern pine nurseries, deficits in rainfall are made up from demountable overhead sprinkler lines supplied from permanent underground mains and oscillated automatically by water motors. Such sprinkling systems usually require 8 or 9 hours to apply the equivalent of 1 inch of rain. Semi-permanent rotary sprinklers have been used in a few nurseries of intermediate size, and some small nurseries have been watered with various portable sprinklers (Weddell, 1935)(___). Watering southern pine seedbeds by surface or subsurface irrigation has proved impracticable.

More than any other nursery operation, watering depends on the personal judgment of individual nurserymen. As a general rule, timing of watering is more important than the exact amount of water applied, particularly until the roots have reached a depth of 4 or 5 inches and enough primary needles have developed to shade the soil considerably. Excessive watering should always be avoided, however. It not only increases costs, but may leach nutrients out of the soil. An inch of water at one time is the usual maximum. Watering should always be stopped before it results in appreciable sand splash, run-off, or sheet erosion, and it should be reduced or withheld if damping-off (p.248) occurs.

The seedbeds must be thoroughly soaked right after sowing and kept continuously moist as long as the bed covers are in place. Drying of the surface soil under the covers for even a day or two may cause heavy losses of germinating seed, particularly if it has been stratified. Beds must be kept equally moist for the first 2 or 3 weeks after the removal of cloth covers.

Need for watering can best be judged from the portions of the seedbed area which dry out most rapidly. Until roots reach a depth of 5 inches and tops shade the ground well, the beds should be watered whenever the soil in those portions dries visibly to a depth approaching 1 inch.

Surface-soil temperatures high enough to be injurious may occur during the first weeks following the removal of the bed covers, when southern pine seedlings seem most vulnerable to heat (p. 238). Watering during the heat of the day may reduce surface-soil temperatures by as much as 20° F. (Anonymous, Surface soil temperature, 1938) (___), and may prevent extensive losses if begun promptly at the first sign of heat injury. Wide observations over many years have shown no instance of injury to coniferous nursery stock from watering

in full sunlight (Davis, Wright, and Hartley, 1942; Davis, Young, Latham, and Hartley, 1938; Hartley, 1935; Wakeley, 1935)(___, ___, ___, ___).

Application of about $\frac{1}{2}$-inch of water at a time will stop wind erosion of surface soil between the removal of bed covers and the beginning of rapid top growth in June or July.

During dry periods, seedbeds must always be watered thoroughly before being weeded by hand or with mineral spirits.

From early June through perhaps the first half of August the increasing demand of the seedlings for water may usually be met by watering whenever rain for the past week has totaled less than an inch and there is no promise of rain, or when the top 2 inches of soil in the more droughty parts of the nursery become visibly dry. In some nurseries the wilting of young, succulent broad-leaved weeds gives warning that water is needed. Deeper seedling root systems make exact timing of watering less important during this period than in the first part of the growing season. A study of 225,000 longleaf pine seedlings showed no significant differences in the numbers and sizes of longleaf seedlings produced under equal amounts of water applied in light and frequent and in heavy and infrequent sprinklings (unpublished data). Theoretically, however, the latter would waste less water by evaporation and might (Marshall, 1931; Marshall by Shirley, 1931; Shirley and Meuli, 1939)(___, ___, ___) produce planting stock more resistant to drought. Shortleaf seedlings receiving equal total amounts of water survived signification better when the water was applied at 4-day intervals instead of in correspondingly smaller dosages each day (Chapman, A. G., 1944)(___).

Extra watering during the hottest hours of the day may sometimes be necessary during the summer months to help control red spider or Sclerotium bataticola (pp. 244 and 255).

Most nurserymen reduce or stop watering from mid-August or early September onward, to "harden off" the stock. This appears sound practice, not only to save costs, but also to improve the physiological quality (pp. 286 and 290) of the seedlings (Kelley, Hunter, and Hobbs, 1945; Marshall, 1931; Marshall by Shirley, 1931; Shirley and Meuli, 1939)(___, ___, ___, ___), and possibly also to improve the development of their roots (Lenhart, 1934)(___). Water must not, however, be withheld to the point of preventing normal growth or of causing mortality from late-season drought. In very dry years perhaps $\frac{1}{2}$-inch of water per week may have to be applied until mid-September or early October. The appearance of the seedlings and the moisture content of the soil are the principal guides. Undersized seedlings on infertile soil should not be watered copiously in the fall to force their growth; the correct treatment for such backward stock is late-season fertilization (p. 300).

Weeds

Weeds compete with seedlings for moisture, mineral nutrients, space, and light; if allowed to grow unchecked, they stunt or even kill large percentages of the stock. In the less fertile soils they may seriously deplete mineral nutrient reserves, especially phosphorus. They attract or support cutworms and red spiders, and possibly nematodes and other pests. If left in the beds until winter, they slow down lifting. Good nursery stock cannot be produced at reasonable cost without controlling weeds, yet control may be expensive too. Hand or machine weeding usually costs from $0.75 to $5.00 or even $7.00 per thousand seedlings produced, injures seedling tops and roots, and may increase damping-off. Chemical weeding may cost only 5 to 10 cents per thousand seedlings, but requires expensive equipment and if done incorrectly may kill seedlings instead of weeds. (Burton, McBeth, and Stephens, 1946; Cossitt, 1947; Crumb, 1926; Davis, 1941; Davis, Wright, and Hartley, 1942; Klingman, 1948; Lincoln and Isely, 1945; Walton, 1946)(___, ___, ___, ___, ___, ___, ___, ___).

Spring and summer weeds are the main source of trouble. Winter weeds which start up in fall-sown or early spring-sown seedbeds, or before late spring-sown beds are prepared, usually are not a serious problem. They grow slowly and are often small. Many of them die when warm weather comes. Often they can be destroyed by slightly modifying cultural practices, such as choice of winter cover crops, and particularly the date of sowing pine seed.

In most southern nurseries, grasses, or grasses and sedges, predominate among spring and summer weeds, but broadleaved weeds usually are important also. The most troublesome weeds of either class are the rank growers; the abundant, aggressive seeders; those with seeds capable of living one to several years in the ground; those seeding at an early age; those that propagate themselves by stolons, rhyzomes, and bulbs--like Bermudagrass (*Cynodon dactylon* (L.) Pers.), Johnsongrass (*Sorghum halepense* (L.) Pers.), and nutgrass flatsedge (*Cyperus rotundus* L.), known locally as nutgrass or coco grass--; and the hardy perennials. Of more than a hundred species of summer weeds in any one nursery, eight or nine may be particularly obnoxious because of their persistence or abundance (McKellar, 1936) (___).

Nutgrass is spread by toothed harrows or similar equipment capable of dragging its chains of bulbs about, and is perhaps the most difficult of all southern weeds to eradicate (Justice and Whitehead, 1946; Mayton, Smith, and King, 1945; Smith and Mayton, 1938; Smith and Mayton, 1942)(___, ___, ___, ___). Small colonies of nutgrass appearing in nurseries hitherto free from this species should be eradicated, regardless of cost, before they spread.

Indirect Weed Control

The difficulty and cost of weeding may usually be reduced indirectly by: (1) alternating heavy cover crops, such as velvet beans, with pine seedling crops, to smother the weeds and discourage their seeding; (2) killing weeds while small, by repeated cultivation when the beds are in neither cover crops nor pines; (3) mowing or eradicating weeds around the nursery to keep seed from blowing or washing in; (4) avoiding compost material (pp. 304 to 305), manure (Atkeson, Hulbert, and Warren, 1934; Burton and Andrews, 1948)(___, ___), seedbed covering, or other substances containing many weed seeds; and (5) scheduling sowing so that as little weeding as possible need be done while the seedlings are small and easily injured.

Skimping the first two weedings of the season greatly increases the number and cost of later weedings; delaying the first two is even worse. Budgeting money and labor for prompt and thorough early weeding is essential, whether direct control is by hand weeding or other means.

Hand and Mechanical Weeding

Before 1947, practically all southern pine nursery stock was weeded entirely by hand, or by hand in combination with hoeing or machine cultivation. Some hand weeding is a necessary supplement to chemical weeding.

For greatest effectiveness, hand weeding must be done before the weeds are large enough to compete seriously with the pine seedlings or to injure the seedlings while being removed, and before the weeds have produced seeds, bulbs, stolons, or rhyzomes. The worst mistake in most nurseries has been to defer hand weeding too long.

Dry beds should always be watered a few hours before weeding. Weeding on dry ground is slow, and results in breaking off many weeds instead of pulling them up.

Hand-weeded southern pine seedbeds usually require 4 to 7 complete weedings a year. Weeding must be done most promptly and frequently on the most fertile soils. In extreme cases individual beds have been weeded 12 to 24 times in one season. It often pays to keep a small crew patrolling the nursery late in the season to pull any weeds that may have escaped earlier hand or chemical weedings and grown above the tops of the seedlings (Cossitt, 1947; McKellar, 1936)(___, ___).

Depending on seedling age and row spacing, 30 to 50 percent of the surface of drill-sown beds can be freed from weeds, at the time weeding is most needed, by means of narrow-bladed hoes or mechanical

cultivators. Many millions of southern pine seedlings have been weeded mechanically with more or less satisfactory results (Cossitt, 1938; McComb and Steavenson, 1936; Toumey and Korstian, 1942; Umland, 1946)(___, ___, ___, ___). Mechanical cultivators have reduced total weeding costs by as much as 40 percent (Umland, 1946)(___), even though they have had to be supplemented by hand weeding close to and within the rows. Cultivation must be very shallow to avoid injuring seedling roots. The chief drawbacks of mechanical cultivation have been destruction of seedlings at or outside the margins of the rows, mechanical injury to and possible <u>Sclerotium</u> infection of surviving seedlings, and lodging of soil against or on seedlings, especially longleaf, with attendant damping-off. These difficulties have been reduced greatly by using improved cultivator shoes that slice just under the soil surface instead of raking it, and that have side-guards to keep loose dirt away from the seedlings. Latest cultivator designs may be obtained from the Regional Forester, U. S. Forest Service, Atlanta, Georgia.

Chemical Weeding

In 1946 and 1947, nursery specialists in the South and elsewhere adapted to coniferous seedbeds a method of weeding carrots and parsnips by spraying with undiluted mineral spirits [31] (Cossitt, 1947;

31/ Attempts to weed southern pine seedbeds with chemicals began in 1924, but until 1946 were not successful. Chemicals found partly or wholly ineffective in southern pine nurseries, or for one reason or another inapplicable under southern nursery conditions, include chloropicrin, Dowicide-H, ferric chloride, fuel oils, sulfuric acid, tetramethyl thiuramdisulfide, zinc chloride, zinc sulfate, and 2,4-D (2-methyl-4-chloro-phenoxyacetic acid) and some of its compounds (Anderson and Wolf, 1947; Benedict and Krofchek, 1946; Cossitt, 1947; Johnson, A. G., 1947; McKellar, 1936; Mitchell and Brown, 1947; Riker, Gruenhagen, Roth, and Brener, 1947; Stoeckeler, 1948; Wakeley, 1935; Weaver, 1947)(___, ___, ___, ___, ___, ___, ___, ___, ___, ___).

Eliason, 1948; Lachman, Cir. 120, 1945; Robbins, Grigsby, and Churchill, 1947; Stoeckeler, 1948)(___, ___, ___, ___, ___). Properly applied, the mineral spirits cause little or no injury to southern pine seedlings, and quickly kill a great majority of common weed species, including most of those particularly abundant or hard to eradicate in southern nurseries. By the end of 1949, practically all of the 200 million pine seedlings being produced in the South were being weeded with mineral spirits. The new method reduced weeding costs to 5 or at most 10 cents per thousand seedlings produced. There has been no indication that its use lowers plantation survival or harms the nursery soil.

Mineral spirits (common dry cleaning fluid, "Stoddard Solvent," "Sovasol -- No. 5," "Varsol," "Stanisol," "Sohio Weed Killer," and the like) derived from naphthenic petroleum contain about 15 percent of aromatic components, which are thought to be what kill the weeds. Under circumstances not yet fully understood, mineral spirits may injure or even kill southern pine seedlings. These circumstances may occur in any nursery through some combination of atmospheric and soil conditions and stage of seedling development. Unless any proposed date, dosage, and time-of-day of mineral-spirits spraying falls well within previously demonstrated safe limits, a test on small plots should be made before use on seedbeds. The quantity, fineness, and uniformity of spray on such plots must, however, closely match those for large-scale application, or the test may be dangerously misleading.

Weeds which, because of size or natural resistance, are not killed by mineral spirits must be eradicated by hand or other means before they go to seed. The resistant weeds, if allowed to seed, will build up a new weed population which cannot be controlled with mineral spirits. Minimum procedure is to hand-pull all resistant weeds a week or more before final spraying; pulling disturbs the soil and causes seeds of other weeds to germinate in time to be caught by the last spray.

Heavy applications have caused some injury to secondary needles in late August and early September. The seedbeds should be freed of weeds and spraying terminated before this time.

Methods of using mineral spirits, as a result of 1947 to 1950 tests in its own and cooperating State nurseries, were developed by the U. S. Forest Service. The following suggestions are drawn from the Service's specifications, but because the method is so new in the South, the current revision should be obtained from the Regional Forester, U.S. Forest Service, Atlanta, Georgia.

1. Equip sprayer with low pressure manifolds, installed to permit low-capacity spraying for weed control and high-capacity with insecticides or fungicides, and with teejet nozzles which throw a fan-shaped spray. Nozzles must have 100-mesh screens, and be spaced 20 inches apart on a boom 17 to 19 inches above the bed.

2. Keep the working pressure below 60 pounds per square foot to avoid "fogging". Fogging causes wind drift, which results in irregular application and sometimes severely injures the pines.

3. Regulate rate to avoid injuring the pines. Start spraying 10 to 14 days after removal of seedbed covers or after seedlings emerging through mulch have acquired a healthy

green color, and apply 10 to 12 gallons per acre 2 to 4 times per week 32/. Later, applications of 25 gallons per

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32/ A table of gallons of liquid applied per acre by two different teejets at specified pressures and rates of travel may be found in Catalogue 55, Spraying Systems Company, 3201 Randolph Street, Chicago, Illinois.

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acre about once a week are satisfactory. Invariably, heavy mortality has followed application of 40 to 80 gallons per acre on very young seedlings.

4. Water the seedbeds several hours before spraying, except right after a rain. Water more heavily the older and larger the seedlings. Do not, however, spray seedlings with secondary needles while the foliage is still wet, as injury results. Do not water beds immediately after spraying, as rain or heavy watering soon after spraying reduces the effect on weeds.

5. During the first few sprays of the growing season, avoid spraying at excessively high temperatures and at temperatures below 60° to 75° F.; these increase injury to the pines, and decrease weed killing, respectively. Spraying at high temperatures in July and August has, in general, not injured the seedlings and has increased the rapidity and completeness of weed kill.

Allyl alcohol, applied to the soil at the rate of 360 pounds per acre several days before sowing, has increased emergence and survival of slash and longleaf pines, and has given excellent early-season control of weeds, including several species resistant to mineral spirits. The same substance has proved effective in weeding red pine in the Lake States. Allyl alcohol is dangerous to handle, but if means can be devised for applying it safely and it is found to have no harmful effects on the soil, it may prove a valuable supplement to weeding with mineral spirits. (Anonymous, "weeds", 1948; Lindgren and Henry, 1949)(___, ___, and unpublished data).

Shading

Because of its extensive use with northern species, shading of seedbeds in the spring or summer was thoroughly tried in the early years of southern pine nursery practice. It was soon found both expensive and unnecessary. It did not consistently increase germination. It frequently increased damping-off, and tended to make seedlings

too tall and slender, to delay formation of secondary needles, to affect root development unfavorably, and to reduce plantation survival (Huberman, Jour. Forestry, 1940; Wakeley, 1935)(___, ___). In one study, shaded seedlings survived only 19 percent the first year in the field and produced only 261 cubic feet of wood per acre in ten years, as against 40 percent and 561 cubic feet for unshaded check seedlings (D. A. Anderson, Texas Forest Service, personal communication). Since 1935 practically no southern pine nursery seedlings have been grown under shade.

Shades on small portions of the beds are, however, useful in diagnosing injuries suspected of being caused by drought and heat, red spider, Sclerotium bataticola, and possibly erosion caused by rain or sprinkling. The shades can be made of light cotton fabric or of lath, supported about 20 inches above the bed. If the changes they produce in temperature or moisture control the injury, similar changes can usually be produced over large areas by increased watering, or by mulching.

Seedbed Cultivation

Except for weed control, surface cultivation of southern pine seedbeds is used only on a few peculiar nursery soils and cannot be generally recommended. The alleged benefits of such cultivation--breaking up surface crust, reducing damping off, increasing water absorption, reducing water loss, and stimulating seedling growth--have not been generally or strikingly demonstrated in southern pine nurseries.

Cultivation has several serious disadvantages. It requires drill-sowing; for application beyond the early months of the growing season it requires fewer than 8 drills to the 4-foot bed. Hand cultivation is extremely expensive; machine cultivation requires special equipment in addition to the cost of machine operation. Hand and especially machine cultivation increase sand-splash of longleaf pine (Davis, 1941)(___), and cause mechanical injury (p. 258) to all species. In one study, machine cultivation, in addition to increasing the cost per bed, reduced the number of plantable seedlings by 16 percent (unpublished data).

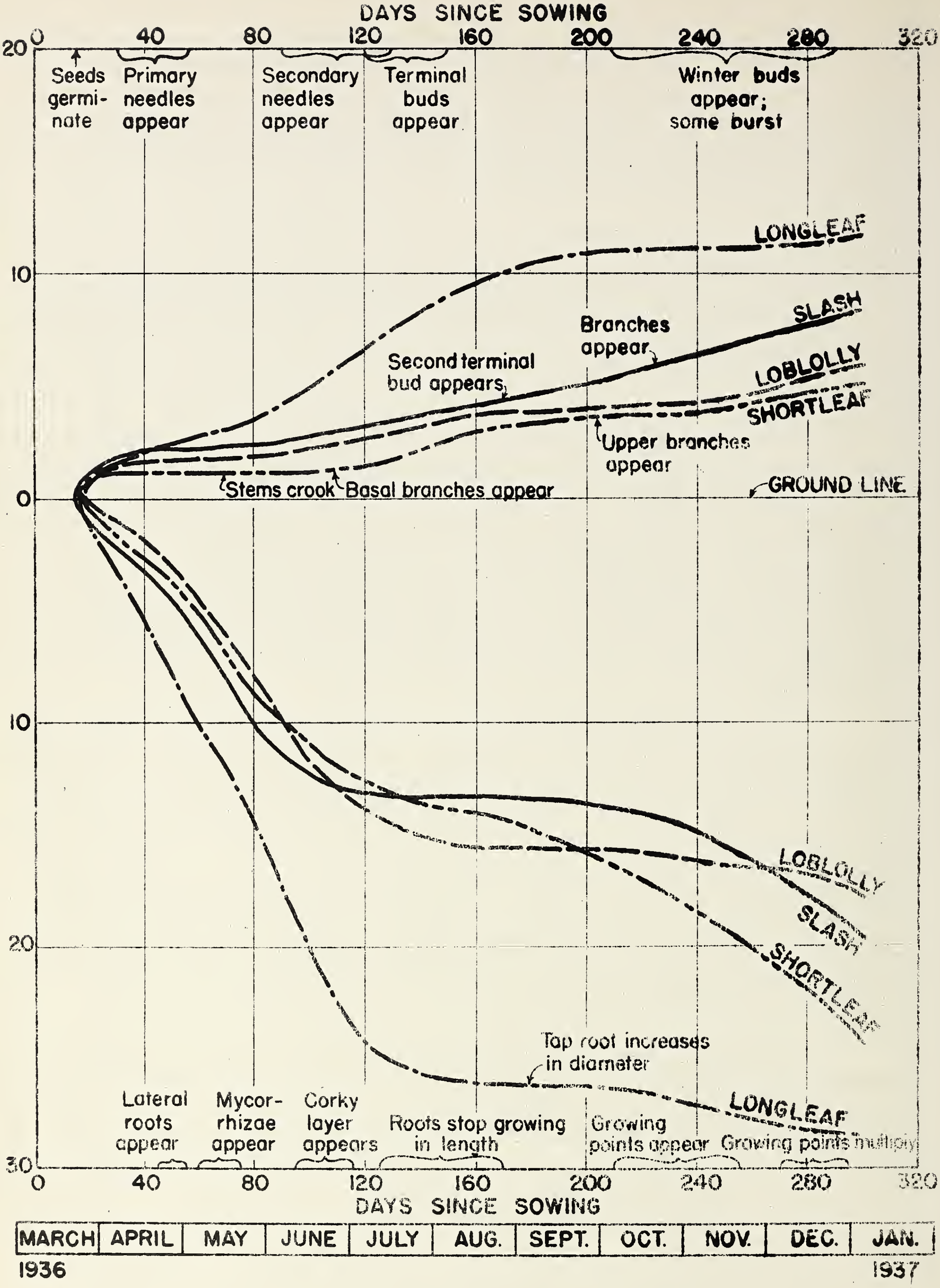

Figure 22.--Normal development of seedlings of the four principal southern pines under practices standard at the Stuart Nursery, near Alexandria, Louisiana, in 1936. (Adapted from (Huberman, Ecology, 1940)(___).)

Three facts shown by the study are thought to have a direct bearing on the evaluation of southern pine seedling grades (pp. 274 to 292) and on the initial survival of planted southern pines. Incidentally, these facts make it questionable whether the term "dormant", or even "top-dormant" may correctly be applied to southern pine seedlings during the ordinary winter lifting and planting period.

First, the study confirmed previous observations that root growth of southern pine nursery seedlings increases about the time top growth decreases in the fall, and remains very active throughout the lifting and planting season. This has been found true as far north as Maryland.

Second, in addition to forming and then promptly elongating and opening a distinct set of buds during the summer (two sets of such buds in slash pine), each species opened an appreciable percentage of its winter buds just before or during the usual lifting season. This common phenomenon and its possible effect on initial survival have been the subjects of much speculation. In the light of the present study it can hardly be considered abnormal , and, as will be shown later (pp. 329 to 332), such breaking of winter buds does not necessarily reduce survival.

Third, the dry weights of the seedlings, and particularly of their tops, increased greatly between the first week of December and the first week of January. During this period few winter buds opened, and there were negligible average increases in stem lengths, stem diameters, numbers of needles, or needle lengths. Yet the dry weights of tops increased 23 to 82 percent (table 18), depending upon species. In the climate of the Stuart Nursery, much of this increase in dry weight of the tops seems clearly attributable to the elaboration of food during the period in question and to the storage, in the stems, foliage, and buds, of the food not needed for the active root growth then taking place. Such accumulation of food reserves presumably has an important favorable effect on survival after planting (p. 288).

At lifting time, all years combined, the longleaf seedlings studied in the Stuart Nursery averaged nearly 12 inches high, measured to the tips of the longest needles, and the slash, loblolly, and shortleaf seedlings averaged nearly 10, 6, and 5 inches, respectively, measured to the tops of the stems. These are perhaps below the averages for southern pine nurseries in general. Some nurseries regularly ship loblolly stock 10 to 12 inches high and slash stock 14 to 18 inches high. On the other hand, longleaf seedlings only 6 inches high, slash and loblolly only 5 inches high, and shortleaf only 4 inches high are generally accepted for planting and frequently make excellent survival and growth (pp. 279 to 286) (Chapman, A. G., Jour. For., 1944)(___). Final heights attained by

Table 18.--Mean dry weights of tops and roots of Stuart Nursery seedlings at specified intervals during the 1936-1937 season, after Huberman (Huberman, Ecology, 1940)(___)

Date	Days after sowing	Top weights: Mean	Top weights: Increase 1/	Root weights: Mean	Root weights: Increase 1/	Top weights: Mean	Top weights: Increase 1/	Root weights: Mean	Root weights: Increase 1/
		Grams	Percent	Grams	Percent	Grams	Percent	Grams	Percent
		- - - Loblolly Pine - - -				- - - Slash Pine - - -			
April 1	20	0.01	...	0.01	...	0.01	...	0.01	...
April 22	42	.01	0	.01	0	.03	200	.01	0
May 13	63	.05	400	.03	200	.08	167	.05	400
June 3	84	.09	80	.05	67	.15	88	.08	60
June 24	105	.21	133	.10	100	.25	67	.09	13
July 15	126	.26	24	.11	10	.47	88	.14	56
Aug. 12	154	.72	177	.22	100	.85	81	.23	64
Sept. 9	182	1.06	47	.23	5	1.06	25	.30	30
Oct. 7	210	1.70	60	.42	83	2.01	90	.44	47
Nov. 4	238	1.37	-19	.43	2	1.86	-7	.54	23
Dec. 2	266	1.68	23	.75	74	2.19	18	.62	15
Jan. 6	301	2.07	23	.90	20	3.41	56	1.11	79
		- - - Longleaf Pine - - -				- - - Shortleaf Pine - - -			
April 1	20	.03	...	.01	...	.01	...	.01	...
April 22	42	.07	133	.03	200	.01	0	.01	0
May 13	63	.17	143	.08	167	.04	300	.03	200
June 3	84	.41	141	.20	150	.05	25	.05	67
June 24	105	.73	78	.32	60	.12	140	.06	20
July 15	126	1.03	41	.36	13	.22	83	.10	67
Aug. 12	154	1.41	37	.56	56	.49	23	.15	50
Sept. 9	182	1.76	25	.75	34	.88	80	.24	60
Oct. 7	210	2.23	27	.86	15	1.14	30	.36	50
Nov. 4	238	2.36	6	.96	12	1.04	-9	.58	61
Dec. 2	266	2.77	17	1.26	31	1.36	31	.86	48
Jan. 6	301	5.03	82	3.33	164	2.24	65	1.65	92

1/ Since previous weighing.

loblolly seedlings in one study of soil texture and fertility ranged only from 2.3 to 3.8 inches (Andrews, 1941)(___). Absolute heights, diameters, or weights of southern pine seedlings are at best rather inexact indicators of normality or abnormality, because seedlings that would be abnormally small for one nursery might be of normal size for another with a different soil or a shorter growing season. Conspicuous changes in size from year to year in a nursery may, however, be valuable clues both to the pattern of normal development and to incipient soil deterioration.

Mycorrhizae appeared fairly early in the development of the seedlings in the Stuart Nursery study (fig. 22), and were abundant on all lots of the stock at lifting time. Mycorrhizae may be described roughly as mantles or sheaths of fungus tissue covering very short seedling roots and in part entering into or between the root cells. They appear to the naked eye as tiny, usually light-colored, forked or fingerlike growths on the tips of the rootlets. Several forms occur, the commonest of which are probably important in water absorption and mineral nurtition, and possibly essential to growth or even to survival of several pines, including loblolly, slash, and shortleaf (Auten, Jour. Agr. Res., 1945; Gast by Huberman, 1937; Gast by Kittredge, 1937; Hatch, 1936; Latham, Doak, and Wright, 1939; Miller, F. J., 1938; Rayner, 1948; Young by Hatch, 1936; Young, 1940)(___, ___, ___, ___, ___, ___, ___, ___, ___). Ordinarily they are abundant on good stock and present to some extent even on poor seedlings, in almost all southern pine nurseries. Scarceness or absence of mycorrhizae, or the appearance of unusual forms on obviously unhealthy stock, should be considered a suspicious abnormality.

Root hairs were not observed on the seedlings in the Stuart Nursery study. They do occur on southern pine seedlings, and have been reported on loblolly and shortleaf pines 10 and 11 years old. Abundant root hairs (though far less abundant than on hardwood seedlings of the same age) have been observed on loblolly pine seedlings 7 weeks old. They occur principally on the youngest portions of long roots. They are destroyed, however, by the formation of mycorrhizae, which also prevents the formation of new root hairs. Although their presence has erroneously been assumed, root hairs seem not to have been observed on normal southern pine seedlings at lifting time. If they do occur at this stage of seedling development, they probably are far less important absorbing organs than are mycorrhizae. (Kozlowski and Scholtes, 1948; Reed, 1939)(___, ___).

In many if not in all nurseries, a crook at ground level is a normal characteristic of shortleaf pine seedlings. In some nurseries this appears on the larger and more vigorous seedlings but not on overcrowded, weak, or otherwise backward stock. In the Stuart Nursery study, in 1936, such crooks developed on shortleaf seedlings about the middle of May (fig. 22).

Although cold seldom affects the color of longleaf seedlings, slash pine seedlings are likely to turn bronze-colored or bronzy-purple, shortleaf bluish or purplish, and loblolly a duller green or somewhat blue, with the first hard frost. These color changes are normal, do not affect survival, and should not be confused with color changes caused by nutrient deficiencies or other injuries (p. 260).

NURSERY INJURIES AND THEIR CONTROL 33/

33/ Upwards of a hundred reports, memoranda, letters, and personal communications, in addition to the printed and processed references cited, have been drawn upon for the information in this section. Acknowledgment is hereby made to personnel of the U. S. Bureau of Entomology and Plant Quarantine, the U. S. Bureau of Plant Industry, Soils, and Agricultural Engineering, the U. S. Forest Service, and various State forest services for such unpublished information not specifically credited in the text. This entire section has been read and approved by specialists of the Bureaus of Entomology and Plant Quarantine and of Plant Industry, Soils, and Agricultural Engineering, and in the Regional Office of the U.S. Forest Service at Atlanta, Georgia.

Control of nursery injuries depends on anticipation or early discovery and identification, and on prior or immediate application of the specific treatment for each. Early discovery of injuries demands daily inspection of the nursery. Prompt treatment often requires that a spray rig and all necessary chemicals and supplies be on hand before the trouble starts. The following pages describe, within each of several classes, the major injuries, and a few minor ones sometimes confused with them, as nearly as possible in the order of their appearance after sowing. Recommended insecticides, fungicides, and the like, and details of their application, are described on pp. 508 to 536.

Climatic Injuries

Their occurrence during or shortly after extreme weather conditions makes most climatic injuries easy to recognize. The exceptions are drought-injury and heat-injury, which sometimes are difficult to tell apart.

Freezing may kill part or all of the tissues of newly germinated seedlings, and the frozen tissues dry up or decay. Freezing seldom involves all of the crop in large nurseries, but may be extremely destructive in particular beds. Fall-sown longleaf is most likely to freeze, particularly just after the removal of cloth seedbed covers. Pine straw covers may reduce injury, but the principal safeguard is to avoid sowing during periods which local weather records show to be hazardous. Because of the period when freezing occurs, ruined beds can usually be resown.

Frost-heaving results from repeated freezing and thawing of the soil. It works young seedlings upward until part or all of the root is exposed, and they die. Frost-heaving is most frequent in

the more northerly nurseries, and on heavy, poorly drained, or temporarily overwet soil. Leaving pine-straw bed covers in place after germination may reduce or prevent frost heaving, but the best safeguard lies in the judicious timing of sowing. Severe injury usually takes place early enough in the year to permit re-sowing the beds..

Hail destroys seedlings, usually while they are in the cotyledon or early primary needle stage, or injures them enough to reduce later survival or growth (Davis, Wright, and Hartley, 1942) (___). Hail is likely to affect a larger percentage of the nursery than freezing or frost-heaving, though at less frequent intervals. It may seriously upset production in an individual nursery, since it may occur too late in the spring to permit resowing. It can be guarded against only by sowing extra beds.

Rain may kill or stunt seedlings by beating them down, washing them out of the beds, inundating them, or covering them with soil. It does additional damage indirectly by removing top soil, increasing incidence of various diseases, washing off fungicides or insecticides, leaching nutrients out of the soil, causing excessive late-season growth, deranging sowing and lifting schedules, and stimulating weeds. Injuries are most serious on the more steeply sloping sites and erodible soils, and in poorly drained places, and are heaviest in the period between removal of covers and the formation of secondary needles; the loss of a million seedlings in a single heavy rain in one nursery has been recorded (McKellar, 1935) (___). Good soil management (including terracing where needed) and retention of pine-straw bed covers after germination reduce losses. Some losses are unavoidable, however, and are one of the principal reasons for sowing 20 percent of extra beds.

Drought and heat during germination and the cotyledon stage often cause heavy mortality. Stunting, fertilizer injury, and outbreaks of Sclerotium bataticola, red spider, and chlorosis may be anticipated from drought and heat in the summer or fall, and late-season drought accentuates damage by white grubs. Drought and heat are most serious on the lightest soils. Well-authenticated cases of direct injury to southern pine seedlings by heat alone are rare (Davis, Wright, and Hartley, 1942)(___), even though nursery surface soil temperatures in June, July, and August very often exceed 120° F. and often exceed 130° F. (Huberman, Ecology, 1940; Huberman, Jour. For., 1940; Wakeley, 1935)(___, ___, ___). Southern pine seedlings evidently are naturally well adapted, in the manner characteristic of some western species (Roeser, 1932)(___), to survive heat.

Among young seedlings injured by heat the stem shrivels and becomes pale; at first there is a definite boundary between the shriveled and healthy parts; affected seedlings usually are scattered rather than in definite groups; and the healthy parts are

relatively slow to decay. Drought affects scattered young seedlings also (and, less frequently, patches of seedlings as well, but without conspicuous evidence of damping-off around the patches); seedlings wilt the entire length of the stem, which sometimes curves before shriveling or rotting at any point; digging may show the soil dry to a level below the seedling roots. On older seedlings heat lesions may appear on one side only (usually the south) or all around the stem; fresh heat lesions are characteristically pale and sharply defined, and are at or just above the soil surface and do not extend below it; older lesions on the larger seedlings may be surmounted by slight swellings. In late-season drought, needles, shoots, or whole plants die in definite streaks or patches sometimes 3 to 10 inches wide. Browning from drought sometimes is inconspicuous until several days after the dry weather which causes it, and death of the roots coincides with that of the tops, or even precedes it (Davis, Wright, and Hartley, 1942; Hartley, 1935)(___, ___).

Thorough watering is the best safeguard against drought. Light watering during the hottest part of the day controls heat injury, and involves no danger to the seedlings (p. 222), but early sowing at adequate rates should make watering for this purpose unnecessary. Retaining part of a pine straw cover after germination reduces both drought and heat hazard to young seedlings. Close weeding reduces drought hazard considerably, as do early sowing, increasing soil organic matter, improving soil tilth, and, in some instances, reducing the elevation of seedbeds above the paths.

Wind accentuates the danger of drought, and in some nurseries removes much surface soil. Wind-blown sand killed an estimated 16 million tender young slash pine seedlings in one southern pine nursery in 1947. Watering during dry, windy periods, early sowing with stratified seed to insure early establishment of full stands, retention of pine straw on the beds after germination, and increasing the organic-matter content of the soil all help to reduce wind-damage. In nurseries subject to constant strong winds during the spring or summer, planting windbreaks has reduced the injury.

Birds, Mammals, and Crustaceans

Birds are one of the greatest early hazards in practically all southern pine nurseries. Mourning doves, meadow larks, bobolinks (ricebirds or reedbirds), various blackbirds, domestic pigeons, cardinals, bobwhite quail, and various sparrows are the most troublesome species. They not only eat the seed but kill or severely injure newly germinated seedlings by clipping off cotyledons with seed coats still adhering. They may get large quantities of seed through light or ragged cloth seedbed covers or light pine straw covers or may even tunnel under a heavy pine-straw cover. Damage rises to a peak when seedbed covers are removed and often continues until the seed coats have dropped from the cotyledons.

The most effective controls have proved to be 9- or 10-ounce burlap or close-woven Osnaburg seedbed covers, automatic exploders (Crowl, 1939)(___) utilizing calcium carbide to make a loud noise every few minutes, and patrols of men or boys either afoot or on bicycles. Patrols must be on duty throughout the daylight hours from the first removal of covers until the seedlings have passed out of danger. Several species of birds, especially doves, are most destructive at dawn and dusk. Patrolmen use blank cartridges, air rifles, slingshots, or watchmen's rattles to scare the birds away. Killing most species is illegal, and is undesirable because they consume cutworms and other insects. Screening the beds is too expensive; also, it may increase damping-off.

Mice have seriously damaged a few southern pine nurseries, but they seem to strike far less often than birds, and on smaller areas within a nursery. Meadow mice, of the genus *Microtus*; pine mice, of the genus *Pitymys*; white-footed mice, of the genus *Peromyscus*; or house mice (varieties of *Mus musculus*), may take seed before or in the early stages of germination, or, much more rarely, injure the roots of seedlings. White-footed mice are notoriously fond of conifer seed. In many instances pine mice are the cause of injury for which moles are blamed. Control requires constant, close inspection to catch the damage when it starts, and immediate use of poisoned bait attractive to the species involved. Recognition of characteristic burrows in grass around the nursery, or of the mice themselves if specimens can be caught (Garlough and Spencer, 1944)(___), aids in selecting the most effective bait.

Moles are often beneficial, since they feed mostly on insects, including white grubs. In seedbeds, however, their tunneling, and perhaps some feeding on roots, may destroy enough seedlings to justify trapping. Suitable traps (Silver and Moore, 1941)(___) can be obtained from agricultural supply houses.

In nurseries west of the Atchafalaya River in Louisiana, *pocket gophers* (p. 382) have sometimes injured or killed quantities of seedlings in the fall by smothering them under their mounds of earth, or by eating roots or whole seedlings. They can be controlled by persistent trapping or poisoning.

Crawfish (*Cambarus* spp.) find good nursery sites too dry for them. In poorly drained beds on some soils, however, they have smothered considerable numbers of seedlings under the mud tubes they build up around the mouths of their burrows. Dropping a little turpentine, creosote, or other toxic substance into every burrow controls them, but it is much cheaper and more effective to spray cottonseed or ground corn cobs heavily with DDT and scatter a few seeds or fragments on each square yard of the infested area (Davison, 1947)(___).

Insects and Arachnids 34/

34/ Some of the insecticides recommended here seem likely to become outmoded by the current rapid development of new substances. Nurserymen concerned with insect control should keep informed about improved insecticides by consulting their State agricultural experiment stations and the U. S. Bureau of Entomology and Plant Quarantine, Washington 25, D. C.

Cutworms, the caterpillars of several moths of the family Noctuidae (Phalaenidae), bite off and kill southern pine seedlings in the primary needle and especially in the cotyledon stage, and occasionally attack and kill seedlings in the secondary needle stage.

Attacks on seedlings in the secondary needle stage have been infrequent but sometimes startlingly destructive; during a single week in July, cutworms have killed more than a million longleaf seedlings in one nursery (Wakeley, 1935)(___). Early season attacks have been less conspicuous, but more frequent, and probably more serious in the aggregate. The meager data available suggest that small populations of cutworms, feeding each year on very young seedlings, may be one of the important causes of low tree percent in many southern nurseries. Furthermore, the possible appearance of large and enormously destructive populations early in any season (Craighead, 1950; Crumb, 1926; Lincoln and Isely, 1945; Walton, 1946)(___, ___, ___, ___) must not be overlooked.

Cutworm injury in the cotyledon stage becomes noticeable as a sudden thinning, either uniform or patchy, of the seedling stand. Cutworm damage is sometimes mistaken for damping-off, but close examination will show that the stems have been bitten completely or partly through at or near the surface of the ground. Where cutworms have eaten the tops of seedlings in the cotyledon stage, tiny seedling stumps in the bare patches may be the only evidence. In the primary needle stage, parts of tops may remain and some stems may be only partly severed. In the secondary needle stage, the cutworms chew both the needle-bases and the bark and stems at and just under the surface of the ground.

Cutworms vary in size, depending on species and stage of development, and reach maximum lengths of $1\frac{1}{2}$ to 2 inches. Caterpillars of most species are smooth. By day they may be found just under the soil among or near injured seedlings or hidden under other vegetation, usually in a curled position (fig. 23, A and B). Their presence may be verified (Crumb, 1926)(___) by scattering large handfuls of dock, chickweed, clover, or other plants that they eat, on unsown beds or other bare ground; any caterpillars found within

two or three days on or slightly under the soil surface beneath such plant material will very probably be cutworms.

Figure 23.--A and B, cutworms; C, adult mole cricket; D, larvae of Leconte's sawfly at various stages of development; E, May-beetle larva (white grub). (Photos by Bureau of Entomology and Plant Quarantine.)

Cutworms hatch from eggs laid in late fall or early spring. The moths prefer weedy or grassy areas for egg-laying. For this reason, areas in fall or winter cover crops or with a growth of early spring weeds may be found heavily infested with cutworms when made into spring-sown seedbeds. Since cutworms can cross plowed or bare soil more easily than most insects, they may also invade seedbeds adjacent to such cover crops or weedy areas.

Where early season attacks occur regularly, they may be prevented or controlled with chloropicrin, benzene hexachloride, chlordane, or DDT. Where outbreaks occur without warning after the beds have been made, or if the cutworms attack seedlings with secondary needles, the best and perhaps the only recourse seems to be poisoned bait, applied within 24 to 48 hours after the start of the attack. Collection of the worms by hand just after dawn may be effective on small areas (Crowl, 1940)(___).

Adult <u>mole crickets</u>, <u>Scapteriscus</u> <u>acletus</u> R. and H. or <u>S. vicinus</u> Scudd. (Wisecup and Hayslip, 1943)(___) sometimes damage southern pine seedlings, especially small ones, both by feeding on the roots and by tunneling the soil surface. The insects are about $1\frac{1}{2}$ inches long and $\frac{1}{4}$ inch wide, light brown, yellowish-brown, or greenish brown, and have large, beady eyes and stout front legs with shovel-like feet (fig. 23C). Their distinctive shallow tunnels are arched over with cracked or crumbling soil. Mole crickets are most active at night, at temperatures above 70° F. They are usually controlled with poisoned bait, but sometimes with benzene hexachloride, chlordane, chlorinated camphene, or DDT.

The larvae of <u>Prionid</u> <u>beetles</u> sometimes cut the roots of southern pine seedlings much as do white grubs, though usually earlier in the season. Injury occurs mostly on newly cleared nursery sites, and usually ceases after the first year. It can be prevented or reduced by removing all roots, stumps, and rubbish where the insects breed and from which they spread to attack the seedlings. Growing a soiling crop before the first crop of pine seedlings presumably would eliminate the hazard (Craighead, 1950)(___). Carbon disulfide or methyl bromide will kill the larvae.

Various harvester or mound-building ants, including the Florida harvester ant, Pogonomyrmex badius Latr. (Craighead, 1950)(___), defoliate or cut off seedlings in the cotyledon stage, or cover them with earth from the burrows at any time. These ants may be controlled with calcium arsenate, carbon disulfide, hydrogen cyanide, methyl bromide, benzene hexachloride, chlordane, chlorinated camphene, or DDT, as best suits local circumstances. Any colony of Texas leaf-cutting ants (pp. 384 to 385) within a quarter of a mile of a nursery should be controlled with carbon disulfide or methyl bromide without waiting for signs of injury.

White-fringed beetles (Graphognathus spp.) are introduced insects whose peculiar life history, great fecundity, inconspicuous and easily transported egg masses, and voracious underground larvae make them a serious agricultural pest in several southern States. They are very dangerous to southern pine nurseries both because of potential direct injury to the seedlings and because the stringent quarantines against them may prevent shipment of stock from any nursery in which they occur. They can be kept out of or eliminated from forest nurseries by trap-ditches or by direct treatment of the soil with DDT. (Anonymous, "Civilians," 1945; Anonymous, "beetle," 1947; Metcalf and Flint, 1939; Young, App, Gill, and Hollingsworth, 1950)(___, ___, ___, ___)(Buchanan, 1947)(___)

The adults are snout-beetles, and are flightless because the wing covers are fused together. The beetles are dark gray, slightly less than ½ inch long and less than 1/6 inch broad across the basal half of the wing. The margins of the wing covers are banded with white; there are two pale lines along each side of the head and thorax, one above and the other below the eye; the body is covered with dense, short, pale hairs, longer toward the tip of the wing covers. In side view, the head looks ludicrously like that of a mouse. No male white-fringed beetles have ever been discovered; the females lay eggs without mating. The larvae, which live entirely underground, are yellowish white, legless, sparsely covered with short white hairs; their backs are evenly rounded upward; and their maximum length is about ½ inch. (Metcalf and Flint, 1939; Young, App, Gill, and Hollingsworth, 1950)(___, ___).

Nurserymen in or near zones of white-fringed beetle infestation should consult the State plant board or State entomologist, the U. S. Bureau of Entomology and Plant Quarantine, or the State agricultural experiment station, well in advance of sowing and again before lifting in the fall, to get the latest information on quarantines, inspection, and methods of control. Any adults or larvae suspected of being white-fringed beetles should be reported immediately to the same authorities, with specimens (in alcohol) for identification.

Sawfly larvae (p. 387 and fig. 23D) sometimes kill and more often seriously weaken seedlings by feeding on the foliage in the summer or early fall. A small infestation one year may breed a costly outbreak the next. The larvae should be controlled promptly with arsenate of lead or DDT.

"Red spiders"--the common mite Tetranychus telarius L. and related species--may cause extensive yellowing and stunting and occasional dying of southern pine nursery seedlings. "Red spiders" are almost too small to see without a hand lens. Some are yellow or greenish instead of red. When mature they have eight legs. In hot, dry weather they multiply with extreme rapidity. Their life history makes two or more treatments at 10- to 14-day intervals, with Bordeaux mixture, cube, lime-sulfur, nicotine sulfate, rotenone, sulfur, or Parathion, necessary for control. DDT sometimes increases their number by killing off their natural enemies, and should not be used, even for other pests, if the presence of red spiders is suspected.

White grubs, the larvae of May beetles or June bugs (Phyllophaga spp.) of which there are over 50 species in the South, are potentially very serious in all southern pine nurseries. They probably reduce tree percent a little in most nurseries. Several times they have killed 10 to 20 percent of all stock in individual nurseries. In a few nurseries, notably in Florida and the Carolinas, they have caused occasional losses of 25 to 40 percent of all stock and have killed 80 percent or more or all seedlings in large groups of beds. (Craighead, 1950; Johnston and Eaton, 1939; Johnston and Eaton, 1942)(___, ___, ___).

The grubs feed on the roots of the seedlings. Attacks in the spring usually kill seedlings outright. The more common summer and early fall attacks kill many seedlings and leave many others unplantable for lack of adequate roots.

Most white grub damage is easy to identify. The injured seedlings, usually in patches, turn from faded green to brown. Dry weather accelerates the change. Sickly and dead seedlings are easily pulled up, and reveal the remains of the characteristically eaten-off roots. Sometimes the feeding is on the laterals or lower tap roots, but often all the roots will have been cut off from 1 to 3 inches below the ground surface.

Digging in or around patches of seedlings which have just begun to fade usually turns up the larvae themselves. These vary from 1/8 inch when hatched to 1 inch long when full grown. Young larvae are almost transparent; older ones are a dirty cream color, with hard brown heads, 6 jointed legs, and nearly transparent abdomens. They bend double when at rest or when disturbed (fig. 23E). They crawl legs downward, in contrast to larvae of the southern green June beetle, which crawl on their backs.

The adults are stout, brownish or blackish beetles usually half an inch or more long. They appear in distinct flights in late March and April and sometimes until late in the summer. At night they swarm around lights.

The insects complete their life cycles in three years or in two years or less, depending on species and locality. Some authorities attribute nursery damage mostly to grubs in their second year, but Johnston and Eaton found that the larvae of species important in the Carolinas became vigorous feeders 60 to 70 days after egg laying and that the most severe injury resulted from mid-August to late October feeding by first-year grubs from eggs laid after the seedbeds were sown. In the Carolina nurseries, the grubs migrated only 11 to 16 feet during the course of their lives. (Johnston and Eaton, 1939; Johnston and Eaton, 1942; St. George, 1935)(___, ___, ___).

The grubs may be controlled with carbon disulfide, chloropicrin, ethylene dichloride, ethylene dibromide, benzene hexachloride, or chlordane. On very moist soil, mineral spirits applied to kill weeds has sometimes killed many of them (Eliason, 1948)(___), but should not be relied upon for complete control. DDT in several instances has failed. Sprinkling or flooding the beds with carbon disulfide or ethylene dichloride emulsions may kill the seedlings as well as the grubs. Poisoning the soil with arsenicals in advance of bed preparation is inapplicable in southern nurseries because the characteristically acid southern soils retain the arsenicals for many years in forms that kill the pine seedlings and most other plants (Craighead, 1950; Fleming, Baker, and Koblitsky, 1937; Johnston and Eaton, 1942; St. George, 1935; Wakeley, 1935)(___, ___, ___, ___, ___). White grubs are at their worst in beds sown to pines for two or more successive years and perhaps have been controlled more than realized by the general practice of alternating pines with soiling crops.

Killing adult May beetles with arsenate of lead as they feed on hardwood foliage around nurseries may reduce egg laying in the beds.

Scale insects of the genus *Toumeyella* seriously weaken southern pine seedlings, particularly loblolly and slash seedlings, by sucking the juices from the needles and stems in the late summer and throughout the fall. They rarely kill or stunt seedlings in the nursery, but most infested seedlings die shortly after planting, even if the scales have been killed just before lifting.

Toumeyella scales are plump, grayish-brown, waxy coverings, varying in diameter from that of a small pencil lead to that of a BB shot. They conceal the bodies and eggs of the females. The females exude honeydew, which sometimes attacts ants and usually is turned sooty black, on needles and stems, by the growth of a harmless mold.

It is thought that if the scales are killed early enough to permit some seedling growth between spraying and lifting, the seedlings will survive planting. For this reason, and even more to prevent intensification, spread, and repetition of the outbreak, the scales should be controlled as soon as discovered. Miscible oil emulsions generally control the scale without injuring the seedlings; lime-sulfur, lubricating oil emulsion, nicotine sulfate, DDT, HETP, and Parathion may be effective. Complete control usually requires two or more sprayings at about 10-day intervals. Seedlings still infested at lifting time should be culled.

The Nantucket tip moth (pp. 386 to 387) often kills back the top inch or two of loblolly, shortleaf, and even slash pine seedlings in the nursery, in late August or during September, and winters in the dead tips (Baumhofer, 1936; Eliason, 1948; Hall, 1936)(___, ___, ___).

In most southern pine nurseries, such tip-moth attacks are negligible. They rarely affect more than 1 to 5 percent of the seedlings (usually the tallest), and apparently the seedlings recover without measurable aftereffects. The tip moth population on most southern pine planting sites is so abundant that loblolly or shortleaf seedlings are sure to become much more heavily infested and severely injured after planting than they were in the nursery; slash seedlings become equally infested but without appreciable injury. Under these circumstances, neither treatment of stock in infested nurseries nor culling of infested individual seedlings is justifiable (Baumhofer, 1936)(___).

Special circumstances, however, may necessitate treating or culling. There may be danger of carrying the insect into tip-moth-free areas, especially from northern Arkansas as far north and east as loblolly and shortleaf are planted in the Central States, or quarantines may prohibit shipment of any tip-moth-infested stock. For fall planting of stock from infested areas on sites in uninfested localities, Hall recommends removal of all infested tips or buds before shipment. For spring planting he recommends shipment in screened containers or conveyances, after dipping of all infested stock in white oil emulsion or nicotine oleate at the nursery to kill newly deposited eggs, or else dipping at the planting site. Later work indicates that spraying with DDT every 10 days from first spring appearance of adults until spring lifting may be as effective as and cheaper than dips. Elimination of the insects with either dip or spray depends upon catching them in the susceptible egg and very young larval stages. (Anonymous, Civilians, 1945; Anonymous, Long Island, 1948; Afanasiev and Fenton, 1947; Baumhofer, 1936; Hall, 1936; Meahl, 1948)(___, ___, ___, ___, ___, ___)

Insects of apparently minor importance include aphids, which are sucking insects, and such chewing insects as *Tetralopha* (p. 388), grasshoppers, and adults of several species of beetles. Aphids can be controlled, if necessary, with nicotine dust or nicotine sulfate; *Tetralopha* and the beetles with arsenate of lead; and grasshoppers with poisoned baits. Many of the multi-purpose insecticides have also been reported effective against these and other minor insects, except that DDT tends to increase aphids rather than control them.

Nematodes

Two types of microscopic or nearly microscopic nematode worms may be serious pests in southern pine nurseries. The gall-forming ("root-knot") nematode, *Heterodera marioni* (Cornu. 1879) Goodey, 1932, although it attacks pine seedlings, does so infrequently and seems to cause negligible damage. It is important chiefly because it is capable of destroying green manure crops of several commonly used species; where it occurs, resistant varieties of these green manure plants must be used. Certain species of free-living nematodes may be much more serious on the pines themselves. In 1947 they were discovered to be strongly associated with, if not the direct cause of, a "root rot" which had thrown a 25-million tree U. S. Forest Service nursery out of production. They may be the underlying cause of puzzling ailments in some other nurseries. (Buhrer, 1938)(___) (unpublished data, U. S. Bureau of Plant Industry, Soils, and Agricultural Engineering and U. S. Forest Service).

Controls for free-living nematodes are still in the developmental stage, though in the nursery mentioned, fall sowing of longleaf and certain improved fertilizer practices with longleaf, slash, and loblolly have somewhat reduced injury, and both chloropicrin and ethylene dibromide have given good control.(Lindgren and Henry, 1949) (___).

If seedlings show knotty or galled roots and especially if undiagnosable late-season "root rots" are associated with poor general development, late-season mortality, and poor survival after planting, it is suggested that: (a) specimens of seedlings in various stages of the injury be sent to the State agricultural experiment station and to the U. S. Bureau of Plant Industry, Soils, and Agricultural Engineering, Washington 25, D. C., to be examined for nematodes; and (b) the injured beds be resown to pines the following year after treating portions with chloropicrin, ethylene dibromide, or sodium cyanide and ammonium sulfate and leaving other portions untreated as checks. Cyanimid and methyl bromide are possible alternative nemacides. If root-knot occurs on green-manure crops, the State agricultural experiment station should be consulted for nematode-resistant varieties.

Fungus and Other Diseases

Damping-off is probably the most serious southern pine nursery disease. It affects all southern pines. Annual losses of 1 to 10 million seedlings have been recorded in several individual southern pine nurseries, and 50, 80, and 100 percent losses in particular groups of beds are not uncommon. Damping-off is caused by fungi of several species, one or another of which may kill seedlings from the very start of germination until at least 6 or 7 weeks after emergence, and may kill longleaf seedlings 4 or more months after germination. The commoner phases kill southern pine nursery seedlings under a wide variety of climatic and soil conditions. Damping-off of one or more southern pines has been traced to one or several species apiece of Botrytis, Diplodia (Sphaeropsis), Fusarium, Pythium, Rhizoctonia, and Virticillium; W. C. Davis found Rhizoctonia sp. most frequently associated with damping-off of longleaf pine over a wide territory. S. H. Davis found that Sclerotium bataticola Taub., a common organism in many southern pine nursery soils, caused damping-off of four northern pines. Species of Phytophthora and Cylindrocladium are suspected of causing damping-off of southern pines, and still other fungi may also cause the disease. (Davis, Spencer H., 1942; Davis, Wright, and Hartley, 1942; Davis, 1941; Davis, Young, Latham, and Hartley, 1938; Fisher, 1941)(___, ___, ___, ___, ___).

Five distinct forms of damping-off affect southern pine nursery seedlings:

1. "Pre-emergence damping-off" kills seedlings while they are still beneath the bed cover, probably often while they are still inside the seedcoats. Its importance often may be grossly underestimated because a sparse seedling stand is the only sign of its presence visible to ordinary inspection. It may merge into later and more easily recognized forms of damping-off, and should be suspected when they occur or when nursery germination falls far below laboratory germination percent. Where pre-emergence damping-off is anticipated, its actual occurrence often may be demonstrated by comparing the stands on plots sown in the fall, or very early in the spring, or treated with formaldehyde, with stands on late-sown or untreated plots.

2. The most familiar form of damping-off attacks southern pine seedlings in the cotyledon or very young primary-needle stage, while they are still succulent. It affects them singly at times, but more often in small groups or irregular patches. The roots of the infected seedlings, or at least the upper parts of the roots, die and turn watery brown. The stems wilt and shrivel; the affected portions of the stems turn rather dark, dirty greenish or purplish, shading off gradually into the normal red or green unaffected parts. Seedlings other than longleaf topple over limply; most freshly germinated longleaf seedlings that have damped-off flatten out on the ground like little rimless wheels. Losses from this form usually decrease rapidly about 4 to 6 weeks after emergence. (Davis, 1941; Davis,

Young, Latham, and Hartley, 1938; Hartley, 1935; Wakeley, 1935)(___, ___, ___, ___).

Care must be taken to distinguish the two forms of damping-off just described from damage by cutworms.

3. "Top damping-off", sometimes but not always associated with conspicuous splashing of infected soil, may affect the tops of slash, loblolly, and shortleaf seedlings to a much greater extent than their roots, at a later stage than the preceding form, even as late as May or June. It is particularly likely to affect seedlings in over-dense stands.

4. "Sand splash" is a form of damping-off of longleaf equally likely to affect newly germinated seedlings and those up to 4 months old whenever surface soil is deposited against them or among their cotyledons or needles. Apparently infection enters the seedlings through parts normally above ground, from the surface soil which has come in contact with these tissues. The growth habit of the stemless longleaf seedlings increases susceptibility to this form of damping-off, in which the tips of the cotyledons and needles, and the portions of the roots more than 3/4 inch underground, remain apparently healthy for some time after the bases of the cotyledons or needles have become infected. (Davis, 1941)(___).

5. A form of late damping-off is designated as "root-rot" by some investigators (Davis, Young, Latham, and Hartley, 1938)(___). This form of the disease differs from top damping-off and sand splash in that the causative organism is active principally or entirely below the normal surface of the seedbed. It occurs when pine seedlings are from 3 to 7 weeks old, or older, and have developed stems stiff enough to remain upright for one to several weeks after the seedlings have died. Again, the seedlings may not die, but may suffer repeated loss of the youngest portions of the roots, or of the deepest portions of the tap roots, with or without a stunting of the tops, and sometimes with unusual growth of lateral roots or prolific formation of new roots just above the killed portion of the main root. The more familiar form of damping-off in the succulent stage may merge imperceptibly into this type of "root rot."

Control of damping-off is difficult and uncertain; "the manipulation of shades and control of watering to which freedom from disease is ascribed by many nurserymen are far from being panaceas. It is impossible or impracticable on many sites to keep damping-off within reasonable limits without soil treatments. The soil treatments that have been developed all have limitations" (Davis, Young, Latham, and Hartley, 1938)(___). It is almost impossible to make any statement about incidence or control of damping-off without running into conflicting evidence either in the literature or in practice (Anonymous,

1936; Auten, Jour. Agr. Res., 1945; Baxter, 1943; Boyce, 1948; Davis, 1941; Davis, Wright, and Hartley, 1942; Davis, Young, Latham, and Hartley, 1938; Gruenhagen, 1940; Hartley, 1935; Latham and Davis, 1939; Lynch, Davis, Roof, and Korstian, 1943; Riker, Gruenhagen, Roth, and Brener, 1947; Roth and Riker, 1943; Roth and Riker, 1943; Roth and Riker, 1943; Wilde, 1934; Wilde, acid, 1937; Wilde, 1946; and unpublished data)(___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___, and unpublished data.) The difficulty of control is intensified by variations in nursery conditions which make the damping-off problems of each nursery peculiar or unique. The following facts bearing on the control of damping-off among southern pines seem, however, to be well established.

Prompt spraying with Semesan and perhaps with Bordeaux mixture may control top damping-off or sand-splash, but these are better controlled by care in bed making, sowing, covering, and cover removal, watering, weeding, cultivation, and maintenance of soil organic matter. The other 3 forms of damping-off seem controllable only by the same cultural practices, by soil treatments applied at or before sowing time, or by a combination of the two.

Selection of soils more acid than pH 6.0, or artificial acidification of soil less acid than 6.0 with sulfuric acid, aluminum sulfate, or other substances, may prevent damping-off by several species of fungi, but fails to control and may even increase damping-off by others, particularly Rhizoctonia spp. Further acidification of already acid soils may make mineral nutrients less available to the pines, and in extreme cases may injure the pines directly.

Treatment of the soil with formaldehyde has often, though not always, controlled pre-emergence damping-off. It seems ineffective against top damping-off and sand-splash. Allyl alcohol (p. 228) has also shown promise as a means of controlling pre-emergence damping-off (Lindgren and Henry, 1949)(___).

Treating the seed with plant growth substances or fungicidal dusts has given virtually no control of damping-off of southern or other pines.

Low vitality of the seed seems invariably to predispose the seedlings to damping-off.

Undecomposed organic matter in any appreciable quantity, very abundant organic matter in any form, or abundant nitrogen in any form and concentrated inorganic nitrogen in particular, or lime, or wood ash, if present during and for some weeks after germination, is extremely likely to increase damping-off. Because of the deficiency of nitrogen and especially of organic matter in many southern nursery soils, their addition at or near seeding time cannot be entirely ruled out, but it should be moderate, cautious, and guided by test applications. If possible, they should be applied well before sowing (perhaps in connection with soiling crops the previous year), or

as top or side dressings after the seedlings have outgrown the danger of damping-off.

November and early December (but not October) sowing, as compared to spring sowing, considerably reduces damping-off of longleaf pine. Early spring as against late spring sowing has reduced damping-off of all southern pines in some years in some nurseries.

Sowing broadcast or in broad bands instead of in narrow drills reduces sand-splash of longleaf, as do all measures which reduce movement of surface soil and its lodgment on or against the seedlings. These measures include leaving part of a pine-straw cover as mulch, reduction of soil wash by proper grading and drainage, increase of soil organic matter, avoidance of soil for seedbed covers, avoidance of cultivation, and substitution of chemical for hand weeding.

In combating damping-off of southern pines, a more general clue than the foregoing facts may be found in the fundamental work of Leach on damping-off of garden and field crops (Leach, 1947)(___). Leach attacked the problem by exposing four species of host plants, known to differ in temperature requirements for optimum early growth, to four species of damping-off fungi, also known to differ in temperature requirements for optimum growth, in different combinations at several temperatures. The results showed that <u>the relative rates of host-emergence and pathogene-growth determined the extent of damping-off</u>. When, at a given temperature, the host plant germinated and grew rapidly and the damping-off fungus grew slowly, damping-off was negligible or light. When temperatures were such that the host plant developed slowly and the fungus rapidly, damping-off was severe.

Exactly the same principle may govern damping-off of southern pine seedlings in the pre-emergence and succulent-stage forms. It seems to explain many of the inconsistencies observed in the occurrence and control of damping-off in southern nurseries, especially since not only temperature but also moisture supply, pH concentration, nitrogen supply, and several other influences manifestly affect, favorably or unfavorably, the relative growth rates of pine seedlings and fungus.

For example, the preference of some damping-off fungi for near neutral and of others for strongly acid soil (Davis, 1941; Davis, Wright, and Hartley, 1942; Riker, Gruenhagen, Roth, and Brener, 1947; Roth and Riker, 1943; Roth and Riker, 1943; Roth and Riker, 1943)(___, ___, ___, ___, ___, ___) may explain why soil acidification is sometimes highly effective (Auten, 1945)(___) and sometimes useless (Davis, 1941)(___).

Again, longleaf pine seed germinates best at relatively low temperatures (p. 183). The principal damping-off fungus attacking longleaf seedlings appears to be <u>Rhizoctonia</u> sp., a "high temperature"

pathogen (Riker, Gruenhagen, Roth, and Brener, 1947; Roth and Riker, 1943; Roth and Riker, 1943; Roth and Riker, 1943)(___, ___, ___, ___). In the light of these facts, the severe damping-off of longleaf sown late in the spring or in October, and the relatively slight damping-off of longleaf sown in early spring or in November, are in harmony with Leach's findings.

As further examples, a high concentration of readily available nitrogen in the soil at the time of germination may increase damping-off primarily because it accelerates the growth of damping-off fungi more than that of pine seedlings. Again, severe damping-off of seedlings from old, incorrectly dewinged, or otherwise weakened seed (Davis, 1941)(___), may be explained by the characteristically slow emergence and slow early growth of such seedlings. Leach reports a closely parallel case of severe damping-off of spinach from seed weakened by storage, as contrasted with that from fresh seed (Leach, 1947) (___).

Close study of the conditions under which damping-off is most prevalent and severe in any nursery, and of those under which seed germinates most rapidly and the seedlings grow most vigorously, may frequently make possible the application of Leach's principle in controlling damping-off even without identification of the fungus involved.

Southern fusiform rust, the second most serious southern pine nursery disease, is caused by Cronartium fusiforme Hedgcock and Hunt, which infects, and fruits on, oak leaves in the spring (fig. 24 A); from the oak leaves passes to and infects the pine nursery seedlings; persists in the seedlings through the summer; and results in swollen cankers or galls on the seedling stems in the fall (fig. 24 B). It apparently kills or stunts few seedlings in the nursery, but seedlings infected in the nursery practically never survive planting (fig. 24 C). Prevalence of the rust on southern pine nursery seedlings with respect to species, places, and years, is practically the same as in southern pine plantations (pp. 391 to 394). (Siggers and Lindgren, 1947; Sleeth, SFN 35, 1940; Sleeth, 1940)(___, ___, ___).

F465226 (fig. 24C)

Figure 24.--A, telia of Cronartium fusiforme on under side of oak leaf in spring--a heavy but not extreme infection. (Photo by G. G. Hedgcock.) B, fusiform rust cankers on 1-0 slash (left) and longleaf pine seedlings in fall. (Photo by U. S. Bureau of Plant Industry, Soils, and Agricultural Engineering.) C, comparative survival of slash pine without (row to left) and with visible rust cankers (blank row behind stake in center) when lifted and planted.

Nursery rust infections totaling 10 to 20 percent of all slash or loblolly seedlings large enough to plant have been common, and 35 to 60 percent have been reported; infections of 2 to 15 percent have been recorded for longleaf 35/. As many as 8 million otherwise

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35/ Although C. fusiforme infects shortleaf pine, fusiform rust on this host seems to be localized to western North and South Carolina. Furthermore, this rust has never been recorded on shortleaf nursery stock.

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plantable slash seedlings have been culled and destroyed in one nursery in one year because of fusiform-rust infection. Expansion of the slash and loblolly planting program since 1947 has greatly increased the seriousness of the rust problem in southern pine nurseries. (Lamb and Sleeth, 1940; Siggers, 1947; Siggers and Lindgren, 1947; Sleeth, 1943)(___, ___, ___, ___)(Unpublished data, U. S. Bureau of Plant Industry, Soils, and Agricultural Engineering)

The only indications of fusiform-rust infection readily visible on seedlings in the nursery are the characteristic stem swellings (fig. 24 B). On slash and loblolly seedlings they usually are spindle-shaped and centered at the point where the cotyledons were attached or an inch or two above it--rarely below it. Incipient swellings on these species often are easier to detect by touch than by sight; older ones are fairly conspicuous and frequently marked by one or more lateral branches arising from or near each swelling. On longleaf seedlings the swellings usually are turnip-shaped rather than spindle-shaped and largely or wholly below the needles and sometimes partly below the root collar. (Davis, Wright, and Hartley, 1942; Sleeth, 1943)(___, ___)

Although seedlings become infected in the spring, conspicuous swellings seldom develop before September or late August, even on slash and loblolly seedlings of vigorous growth or from early sowings. On slash and loblolly from late sowings or of slower growth, and on longleaf seedlings, the swellings may not appear much before lifting time. By the time the swellings appear, the seedlings are long past saving. The percentage of stem-swollen seedlings in unsprayed beds or plots in bad rust years is the best single index to the need for systematic rust control in any particular nursery, and should be recorded as a guide to protection policy in future years.

Control measures must be timed to fit precisely the intricate life history of C. fusiforme (pp. 392 to 394). Pine nursery seedlings can become infected with the rust only in the spring, and only from spores produced on leaves of oaks. They are likely to become heavily infected, however, whenever temperatures between 60° and 80° F. coincide with relative humidities approximating 100 percent

for 18 hours or more during the time in which telia (fig. 24 A) are present in great numbers on oak leaves within a mile or two of the nursery. Production of telia on neighboring oaks and occurrence of weather favorable to infection of the pines vary enormously in different nurseries and years. Conditions likely to result in heavy infection are easy to recognize. They consist of numerous oaks around the nursery, the development of telia on their new leaves, and general likelihood or specific forecasts of weather favorable to spore formation. When all these combine to make hazard high, control measures should be applied with special care.

Control requires weekly spraying with Fermate (preferred), Zerlate, or Bordeaux mixture throughout the period of possible infection of the pines. Even if it means applying the first 1 to 3 sprays on the seedbed covers instead of directly on the seedlings, spraying must start before telia appear on the oak leaves--by March 15 at the latest; a week after the first oak buds in the vicinity have burst, or when the daily average temperature reaches 57° F., if either of these occur before March 15. It must continue until the middle of June. A good spreader and plenty of spray pressure (275 to 325 pounds per square inch) are essential. Infection is most likely during wet weather; therefore, if rain interrupts regular weekly spraying, spray should be applied as soon as the foliage is dry enough to retain it and the ground is dry enough to permit use of the spray rig. In bad rust years, the omission of one spray may waste the benefit of all the others. The prewar cost of 12 to 15 weekly sprayings totalled about 20 cents per thousand trees produced. Such spraying should be standard practice on slash and loblolly, and frequently on longleaf, in any nursery in a locality of high rust hazard or in which 10 or 15 percent of fusiform-rust infection has ever been observed. (Siggers, 1947; Siggers and Lindgren, 1947; Sleeth, 1943)(___, ___, ___)

Culling visibly infected seedlings at lifting time (p. 267) cannot take the place of spraying. Although it improves average survival in the plantation, culling saves none of the money spent in growing the infected seedlings. Neither does it keep the infected seedlings which have failed to develop swellings by lifting time from getting into the plantations, and in the rush of lifting some of the trees with visible swellings also inevitably get by the graders. (Sleeth, SFN 35, 1940)(___).

Late sowing of slash and loblolly substantially reduces fusiform-rust infection (Sleeth, 1943)(___), but does not give complete protection when conditions favorable for infection occur in May. And late sowing is likely to increase losses from damping-off, Sclerotium bataticola, and inadequate seedling growth.

Controlling fusiform rust by eradicating all oaks within 1,500 feet of the nursery has proved expensive and ineffective (Sleeth, 1943)(___).

Brown spot needle blight, caused by *Scirrhia acicola* (Dearn.) Siggers, is the commonest and most serious late-season nursery disease of longleaf pine. It affects the secondary needles only, and ordinarily appears in June or July, but sometimes as early as May or not until August or later. Unless controlled, it grows worse until the seedlings are lifted. Infections too light to weaken longleaf seedlings in the nursery may become more intense after planting and cause ultimate failure. Serious outbreaks sometimes occur on loblolly and slash pine nursery stock--on slash pine particularly beyond its natural range or on very dry or infertile nursery sites (Wakeley, 1935)(___)--but much less frequently than on longleaf. The disease sometimes attacks shortleaf and other southern and some exotic pine nursery stock practically throughout the southern pine region, but all species suffer most seriously in certain territories shown in figure 4 (Siggers, 1944)(___).

Brown-spot infection in the nursery is easily recognized by the ordinary external spots on the needles (p. 398); the irregular distribution of the yellowing in the early stages of these spots distinguishes the disease from the uniform yellowing of chlorosis. "Bar spots" also occur on infected nursery seedlings, but much less commonly than the ordinary type, and less commonly than on seedlings in plantations. The manner and pattern of infection in nurseries are essentially the same as in plantations (p. 398). Infection naturally is likely to be heaviest in nurseries near or immediately adjacent to heavily infected stands of longleaf pine.

Brown spot is easily controlled by spraying the seedlings with practically any fungicide, at frequent enough intervals to protect new foliage as it develops. Spraying with Bordeaux mixture (p. 524) has been standard practice for many years. A final spraying just before lifting is important, particularly in nurseries where brown-spot infection is naturally severe, and most particularly if infected longleaf seedlings are already present on or near the planting site. Four to six sprayings, including the one at lifting time, usually control brown spot satisfactorily, at a total cost (prewar) of 3 to 9 cents per thousand seedlings. In extreme cases, however, a dozen sprayings have been required.

Needle cast caused by *Hypoderma lethale* Dearn. may kill the foliage of southern pine nursery seedlings, especially loblolly, much as it does that of planted and natural trees (p. 401). Needle cast is potentially dangerous and should be controlled promptly when discovered. Repeated sprayings with double-strength (8-8-50) Bordeaux and a good adhesive have been recommended (Davis, Wright, and Hartley, 1942)(___).

Sclerotium bataticola Taub. is a common soil-inhabiting fungus consistently associated with, if not actually the cause of, much seedling mortality from June or July through August, in

nurseries from Georgia and Florida west to Arkansas and Texas. In extreme cases it may kill 50 percent of the seedling stand. The fungus seems to affect shortleaf most frequently and severely, and longleaf least.

According to Sleeth [36/] symptoms and signs of S. batàticola

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36/ Bailey Sleeth, unpublished memoranda, U. S. Bureau of Plant Industry, Soils, and Agricultural Engineering.

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infection on southern pine nursery seedlings are "wilting of new growth at the top, followed by death of the stem and needles below; frequently a constriction of the stem near the ground; and black sclerotia immediately beneath the bark and in the dead tissue; a distinctly dry, dead appearance of the roots. Except for the sclerotia, the trouble might easily be taken for a combination of heat and drought injury." (The sclerotia are small, specialized structures of the fungus tissue, visible to the naked eye, but more easily distinguished with a hand lens.) The fungus, characteristically tolerant of high temperatures (Berkeley, 1944; Chester, 1942)(___, ___), is most likely to occur on southern pine seedlings in the hottest and driest weather. Injuries caused by hand weeding and especially by hoeing and cultivation intensify infection.

Mid-day watering to reduce surface-soil temperatures is the most direct means of controlling S. bataticola. Mulching (as by leaving part of a pine-straw bedcover) and increasing soil organic matter have both been beneficial; so has the avoidance of late sowing (Sleeth, 1943)(___).

Quarantining of infected nurseries or beds, or disinfection of the stock before shipment, is not recommended, as the fungus is of widespread occurrence on other plants and can flourish also on decaying vegetable matter, without living hosts (Chester, 1942)(___).

The Texas cotton root rot, caused by Phymatotrichum omnivorum (Shear) Duggar, attacks southern pines in plantations (p. 403), but does not seem to affect 1-year-old southern pine seedlings even in nursery soils in which it is abundantly present. In the southern pine region, this rot occurs no farther east than southwestern Arkansas and eastern Texas. Authorities see little danger in shipping seedlings from infected beds to planting sites within the range of the root rot, but shipment to areas east of the known range seems questionable procedure (Jordan, et al., 1948)(___). Attempts to eradicate the rot by acidifying the nursery soil with sulfur have not been wholly successful. Infected nursery sites can be avoided by testing them, before development, with cotton or other rot-susceptible plants.

Miscellaneous late-season root rots may be caused by damping-off fungi (including Phytophthora spp., which cause resinous exudations and resin-soaked tissue at the point of first infection), Torula marginata, Poria cocos, Armillarea mellea (Vahl.) Quel. (which forms black shoestring-like fungus strands in the soil), and, doubtless, by other fungi (Baxter, 1943; Boyce, 1948; Davis, Wright, and Hartley, 1942; Hartley, 1935; Jackson, 1945)(___, ___, ___, ___, ___). Any root rot discovered late in the season or at lifting time should be observed and recorded carefully. Root rots affecting any considerable percentage of the seedlings merit investigation by pathologists.

"Smothering fungi" of the genus Thelephora form conspicuous purplish or brown cups or collars around seedling stems, usually in the late fall or winter, and especially on moist sites. Although they sometimes cause much anxiety to nurserymen not familiar with them, these fungi do not seem to be parasitic (Boyce, 1948)(___). The cups rarely smother southern pine seedlings, and usually collapse or disappear with the passage of time or the coming of dry weather. Control with Bordeaux spray has been suggested (Baxter, 1943; Davis, Wright, and Hartley, 1942)(___, ___), but apparently not tried on southern pines.

Chlorosis is a yellowing of part or all of the seedling foliage resulting from the breaking down or non-formation of the normal green pigment. It may appear in June, May, or even earlier, but is commonest during the hot summer months or early fall. Often, though not always, it accompanies or is followed by poor growth or stunting. In some nurseries it reappears in the same places year after year. It seems to be most common, persistent, and detrimental in shortleaf pine seedlings, and least so in longleaf.

The extent to which chlorosis causes the stunting with which it is associated is not known. Apparently it does not directly kill seedlings in the nursery. No records are available of the plantation survival and growth of chlorotic or formerly chlorotic seedlings.

Uniform yellowing distinguishes chlorosis from incipient brown spot. Lack of browning, of lesions on needles or stems, and of any fruiting bodies distinguishes it from later brown spot and from needle cast and Sclerotium bataticola infection. It is difficult to tell from some forms of heat and drought injury, and from "red spider" injury except when the mites themselves are discovered.

Chlorosis has been attributed to an immense number of climatic influences and physical, chemical, and microbiological peculiarities of the soil (Baxter, 1943; Boyce, 1948; Davis, Wright, and Hartley, 1942)(___, ___, ___). In southern pine nurseries it has appeared following application of commercial fertilizers, heavy applications of compost, and the plowing under of green manure crops. It has appeared along terraces--sometimes on the ridges and sometimes in the channels. It has followed dry periods as well as excessive rains.

Clearly defined patches of chlorotic seedlings often mark the courses of old paths and roads, the foundations of old houses, and spots where brush and stumps have been burned.

Most chlorosis clears up spontaneously. Some responds promptly to one or two sprayings, at 10 day intervals, with a 1.0 percent solution of ferrous sulfate ("copperas"). Probably ferrous sulfate should be tried on any patches extensive enough to cause concern. Beyond this, the only treatment that can be recommended is to try to identify and correct the abnormal soil condition with which the chlorosis is associated. Some check on the after-effects of chlorosis on plantation survival and growth is advisable.

Enlarged lenticels occur on southern pine nursery seedlings, usually late in the growing season, much as they do on planted trees (p. 403). They usually indicate a need for improving the drainage, but are otherwise harmless and may be ignored.

Mechanical Injury

Serious mortality during the growing season or heavy culling at lifting time often results from mechanical injury to the seedlings during cover removal, cultivation, hoeing, or weeding. Prevention or control of mechanical injury is usually easy. The main problem is to differentiate mechanical injury from other injuries, and trace it to its source.

Mechanical injuries to seedling stems usually involve either bending (rarely breakage), or removal of bark. Heat lesions and fungus infections leave the bark in place, but discolor it. Mechanical injury seldom causes discoloration unless fungi subsequently invade the injured tissues.

Rapid bark-healing at the point of injury is characteristic of mechanical injuries but not of fungus infection, although swelling may occur above injuries of both types.

Insect injury, as by beetles or grasshoppers, may also remove bark and be followed by healing, but usually occurs at several levels up and down the stems or is concentrated at the tops. By contrast, mechanical injury usually occurs near the ground, sometimes just under the soil surface, and is concentrated at the level of a hoe-stroke or of some projection on a cultivator shoe.

Heat and drought injuries occur in or follow hot, dry weather. Mechanical injuries appear after some cultural operation, regardless of weather.

Heat injuries tend to concentrate on the south sides of seedlings, particularly on the south sides of beds or the north sides of openings in the stand. Mechanical injury usually is independent of compass direction.

Insect and fungus injuries affect seedlings anywhere in the drills, or may occur principally in the interiors of drills. Mechanical injury occurs mostly along the outside margins of drills.

Heat and drought usually affect the smaller seedlings particularly. Insects and fungi, depending on species, frequently affect mostly small seedlings or mostly large ones. Mechanical injury affects seedlings largely according to position rather than size.

Root injuries by insects and fungi occur at varying and frequently at considerable depths; white grub injury is a good example. Mechanical injury usually affects only the roots nearest the surface.

Chemical injuries to needles, as from fertilizer concentration or from sprays, merely brown or kill the needles. Mechanical injury crushes or cuts them or tears them out.

If examination of seedlings by the unaided eye or with a hand lens does not show clearly whether the injuries have been caused mechanically, a number of small test plots should be given a variety of special treatments and reexamined frequently and carefully for contrasting results. The alternative causes of injury suspected will suggest appropriate test treatments, such as omission of cultivation, extra careful hand-weeding, shading to reduce soil temperatures, extra watering, and special spraying with insecticides and fungicides.

Nutritional Deficiencies and Toxic Effects

Size of seedlings.--Within wide limits, absolute size of the seedlings is not a very reliable guide to the adequacy of nutrition. When, however, small seedlings survive less well than equally small seedlings from other nurseries, deficient nutrition should be suspected. It should also be suspected if the seedlings are too small to be planted conveniently or to compete with the vegetation on ordinary planting sites, or if the nursery stock fails conspicuously to attain the same size as in former years. Retarded growth often is a sign of nitrogen deficiency.

"Troughing" consists of failure of the seedlings in the middle of the bed to grow as well as those along the edges. In mild cases, the retardation in growth involves only the later secondary needles. In serious troughing, secondary needles fail to form on the seedlings in the middle of the bed, and the stems (of species other than longleaf) make less growth. In extreme cases, summer and fall mortality

is heavier in the middle than along the edges. Any of these stages gives a bed the appearance of a shallow trough (fig. 25). Marked troughing, formerly (Wakeley, 1935)(___) attributed to insufficient watering and still chargeable to it in some instances, has proved to be in most cases a clear sign of nutrient deficiency.

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Figure 25.--Moderately severe troughing in slash pine seedbed; note retarded growth (shown by dip of rope) and lack of secondary needles in center of bed. Troughing is a common sign of inadequate soil nutrients.

Weeds.--Other things being equal, a weak, sparse, unaggressive growth of weeds is a sign of low soil fertility. It is sad but true that weeds are most troublesome when nutrient levels are at their best for pines.

Color changes.--Yellowing, fading, and browning are symptoms of several injuries previously discussed. A deficiency of nitrogen may cause yellowing less distinct than chlorosis, but still easy to see; such yellowing, usually accompanied by stunting, often occurs when sawdust is added to the soil without also adding enough nitrogen to supply the microorganisms breaking down the sawdust. Phosphorus deficiency (Davis, Wright, and Hartley, 1942)(___) may cause seedlings to turn purple or blue before cold weather (p. 236) and growth often stops almost completely when the color changes.

Browning or burning by insecticides or other sprays, or as a result of excessive use of late-season fertilizers or failure to wash fertilizers off the foliage, is generally easy to recognize. Injuries affect mostly the newest and most tender tissues, or those most directly exposed to contact with the chemicals. With few exceptions, the signs of injury develop within a few days (sometimes within a few hours) after treatment, and are intensified by heat and drought.

Poor initial survival after planting.--If not caused by incorrect treatment during lifting, shipment, or planting, or by some definite plantation injury (pp. 374 to 404), poor initial survival after planting may often be the result of inadequate or unbalanced mineral nutrition in the nursery (pp. 288 to 289).

SEEDLING INVENTORY

Nursery stock produced for sale must be inventoried months in advance of lifting, as a safeguard against accepting more orders than can be filled. Stock produced for home use must be inventoried in time to permit detailed preparations for field planting. Southern pine seedling inventories, particularly where production is reckoned in millions, usually consist of estimates made by counting the seedlings in 1- by 4-foot samples at intervals along the beds. Inventories must not cost more than a few cents per thousand trees shipped. Final estimates showing numbers of plantable trees within 5 percent are greatly to be desired, and are acceptable bases for nursery cost accounts and for technical operations requiring good records of stock quantities. Dubious or less accurate final estimates often require checking or correction by counts or new estimates during lifting and packing.

Common obstacles to meeting these standards for southern pine seedling inventories are: irregularity of seedling spacing or seedling stand density; late-season injuries, as from white grubs or drought; failure of a considerable percentage of seedlings to attain plantable size or grade until the very end of the growing season; and the difficulty or impossibility of detecting some damage, such as root injuries and fusiform rust, until the stock has been lifted.

In practice these obstacles can be largely overcome by: (a) mixing the seed thoroughly before sowing (p. 218); (b) making two inventories, one in July and one in September or October; and (c) correcting one or both inventories by means of data derived from experience or from special samples.

The July inventory is needed for preliminary planning of stock shipments and field planting. It need not be highly accurate, and its cost is kept down by taking only enough samples to give a fair approximation of the total number of living seedlings. The estimate usually is corrected by reducing this total, in the light of past experience, to allow for late-season injuries and usual percentages of culling.

The fall inventory attempts a much closer estimate of the total number of living seedlings and usually also a close estimate of the number of seedlings expected to be plantable at lifting time. In any event, estimates must be reduced to allow for losses during lifting. These standards necessitate more samples, often more detailed examination of samples, and generally better records of past experience than are required for the July inventory.

If seedling development has varied little from year to year and damage is light, past experience may be a reliable guide to the percentage of seedlings, alive in September or October, that will be

plantable when lifted. More frequently, damage is light or is confined to the seedling tops, but seedling development has varied greatly from year to year, or (as in new nurseries) past records are unavailable. Then it is necessary to record, on the basis of top size and condition, the number of plantable seedlings in each inventory sample. Often, root defects make grading by tops unreliable, and then some of the inventory samples must be dug and the number of plantable seedlings in each determined by examining both roots and tops.

The total number of living trees in September or October usually can be determined within 5 percent, and often within 2 or 3 percent, at reasonable cost. Numbers of plantable trees are harder to estimate within 5 percent, because of the errors introduced by mechanical injury during lifting and because of the difficulty the man who makes the inventory in October has in grading the same as those who lift the seedlings in December. The U. S. Forest Service's shipping records have nevertheless repeatedly checked October inventories of plantable stock within 4 percent.

Such accuracy can be attained, however, only by following well-established rules (Schumacher and Chapman, 1948)(___), based upon sound sampling procedure:

1. Sampling must be applied to tolerably uniform nursery units. Occasionally an entire nursery constitutes such a unit. More often the nursery must be subdivided into several dissimilar units, as "fall-sown longleaf," "spring-sown longleaf," "seed from locality A," and so on, which must be sampled separately. It is especially important to make separate units of portions of the stand which differ greatly in seedling density, even if they are similar in other respects. A large, irregular portion of a compartment in which the stand has been made uneven in density and spacing, as by hail or bird damage, should be mapped out as a unit separate from the rest of the compartment.

2. Sampling must be done with an intensity (table 19) suitable to the size of the unit being inventoried, to the uniformity with which the seedlings are distributed in the beds, and to the accuracy of the estimate desired.

3. If seedbeds are of equal size, equal numbers of samples should be drawn from each. If beds vary in size, the number of samples drawn from each should be proportional to bed length. Except where the total number of seedlings is very large and the beds are unusually small--less than 100 feet long--it is well to draw at least two samples from each bed.

4. All sample locations must be drawn strictly at random, with absolutely no exercise of personal judgment. Locations may be established by pacing.

Table 19.--Numbers of samples required to inventory nursery units with degrees of intensity suitable under various conditions [1]

Size of nursery unit: No. of beds 4 by 400 ft.	Size of nursery unit: Number of trees [2]	Total number of samples required to include following percentages of bed areas:- 20	10	5	2	1	0.5	0.25
1	50,000	$\boxed{\boxed{80}}$	$\boxed{40}$	20	8	...	...	...
2	100,000	160	$\boxed{\boxed{80}}$	$\boxed{40}$	16	8	...	...
10	500,000	800	400	$\boxed{\boxed{200}}$	$\boxed{80}$	40	20	...
20	1,000,000	...	800	400	$\boxed{\boxed{160}}$	$\boxed{80}$	40	20
100	5,000,000	...	...	2,000	800	$\boxed{\boxed{400}}$	$\boxed{200}$	100
200	10,000,000	...	...	...	1,600	800	$\boxed{\boxed{400}}$	$\boxed{200}$

1/ Samples are 1 by 4 feet, across the beds. $\boxed{\boxed{\quad}}$ indicates total number of samples suggested for final inventory of uniformly spaced stand or preliminary inventory of very irregular stand. $\boxed{\quad}$ indicates total number suggested for final inventory of exceptionally uniform stand or preliminary inventory of ordinary stand. For extremely irregular stands, intensities of sampling should be increased somewhat above those suggested. For numbers of beds intermediate between those shown, numbers of samples should be interpolated.

2/ Approximate only, assuming a density of slightly more than 31 trees per square foot.

5. If plantable seedlings are to be judged on the basis of both roots and tops, a sample of the samples of living seedlings must be selected at random for digging. Ordinarily 20 samples will reveal any important variation in the plantable percent, and digging more than 20 from each unit is expensive. In extreme cases, however, up to 40 per unit may be needed.

6. Counting and recording of numbers of seedlings in samples must be exact. Sampling frames must be used, and workers should have written directions concerning inclusion or exclusion of borderline trees. The only personal judgment permissible in sampling is in classifying trees as plantable or unplantable.

7. The total net length (exclusive of blank stretches) of the seedbeds in the unit being sampled must be measured exactly with a tape; pacing is not accurate enough.

If these rules have been followed, inventory data can be analyzed like those from germination tests (pp.192 and 193) to forecast probable upper and lower limits of actual nursery output or to compare the effects of different nursery practices. With seedling inventories, however, in contrast to germination tests, numbers of samples need not be kept constant, and the data are not "transformed."

The step-by-step details of seedling inventories are given on pp. 556 to 559.

LIFTING, CULLING, PACKING, AND SHIPPING

The lifting season brings a peak load of nursery work. Careful advance planning and timely purchase of equipment and supplies are required to maintain shipping schedules, which in large nurseries may include a million trees a day. Moreover, since plantation success depends as much upon the quality and condition of the seedlings as upon the way they are planted (p. 315), shipping schedules must be maintained without lowering the technical standards of lifting, culling, packing, or shipping.

Inspection and Certification Before Lifting

It is usually necessary, and always desirable, to have the nursery inspected and the stock certified by the State plant board or equivalent agency (p. 536) just before lifting time. Common carriers will not accept stock for interstate shipment without inspection certificates, and quarantine lines may affect truck shipments within States as well as across State lines. White fringed beetles, Texas cotton root rot, Nantucket tip moth, and other pests discussed under nursery injuries and their control may give rise to quarantine problems in individual States. Even where there is no legal barrier to shipment, inspection may forestall extensive injury to plantations by previously unsuspected pests.

Protective Sprays and Dips

If the stock is to be planted where rabbits bite off a considerable percentage of seedlings, loblolly, slash, and shortleaf pines may profitably be sprayed with a rabbit repellent just before lifting.

Wherever brown spot needle blight is appreciable either in the nursery or in plantations, longleaf should be sprayed with Bordeaux mixture shortly before being lifted. Raw linseed oil, although inconvenient and expensive, seems preferable to other stickers for this final spraying because it lasts exceptionally well.

Dips or sprays at lifting time to control Nantucket tip moth are needed or are effective only under certain circumstances (pp. 246 and 387.

Dips or sprays to increase initial survival by reducing transpiration (p. 343) have not been developed for practical application in southern pine nurseries.

Lifting

One of the nurseryman's greatest responsibilities is to lift the seedlings without injuring them, and particularly without breaking off many lateral roots (pp. 334 to 335).

Seedlings in small nurseries, and special lots of stock in large nurseries, are usually lifted by hand. Roots are pruned to 7 or 8 inches (p. 333) either with shovels, as the first step in lifting, or with hatchets or cleavers after lifting. Injury to the roots, including cutting them too short, is kept at a minimum by using sharp, square-edged shovels; by lifting only when the soil is at a moisture content to crumble easily; and by separating the roots gently from the soil.

The tractor-drawn lifters used in large nurseries consist of variously designed and mounted blades set to undercut the seedbeds at a depth of about 11 inches and to loosen the soil without disrupting it greatly or overturning the seedlings. Descriptions have been published (Lewis and Eliason, 1937; McComb and Steavenson, 1936; Toumey and Korstian, 1942)(___, ___, ___), and specifications for current models may be obtained from the Regional Forester, U. S. Forest Service, Atlanta, Georgia.

Mechanical lifters have the disadvantages of not actually removing the seedlings from the soil, often of damaging the seedling roots, and sometimes of injuring the soil itself. Different nurseries require different lifter designs and operation. Operating lifters on heavy soils when the ground is too dry or too wet, or at too great speed under any conditions, breaks many seedling roots, with consequent mortality after planting (pp. 333 to 335). Mechanical lifting intensifies the problem of keeping the nursery soil in good physical condition (p. 295). After the lifter has undercut the seedlings, great care must still be used in getting their roots out of the ground, by hand or with forks or shovels, and in root pruning, either by hand or on mechanical grading tables. Supervision of the lifting should include occasional sifting of the seedbed soil, and washing and hand-lens examination of seedlings, to see how many small lateral roots are being broken off.

Grading and Culling

Grading (pp. 274 to 292) and culling are integral parts of lifting and packing southern pine nursery stock. Culling usually eliminates 10 to 20 percent of the seedlings as below plantable grade, and an additional percentage of higher-grade seedlings which have suffered mechanical injury or certain fungus infections or insect infestations.

Grading and culling must be done rapidly to keep roots from drying out, and to maintain shipping schedules and keep costs down. They may be done either at the seedbeds by the workmen who separate the seedlings from the loosened earth, or by graders working in buildings or at portable tables screened with cloth to keep off sun and wind. In large, permanent nurseries, grading in a special building is preferable. It concentrates grading and culling in the hands of fewer men, who can be selected, trained, and supervised better than a large, widely scattered crew. The more uniform temperature and humidity in a building increase working efficiency and reduce stock drying. Maximum efficiency usually is reached by grading seedlings on moving conveyer belts, though such belts are impracticable when many rust-infected seedlings must be removed.

It is customary (p. 333) to cull all seedlings with roots cut or broken off less than 5 inches below the root collar. Seedlings with conspicuously split main roots, with broken stems, or with conspicuously stripped lateral roots, root bark, stem bark, or foliage, also should be rejected. Seedlings less severely but still visibly damaged probably should be passed, but, if numerous, should be called to the attention of the lifting crew.

All seedlings infected with southern fusiform rust (fig. 24B) should be culled (pp. 254 and 391 and fig. 24C), as should seedlings infested with live scale insects.

No general rule can be laid down about culling seedlings with root rot. A few decayed roots probably are inevitable in any lot of stock. Widespread occurrence of rot requires both consultation with pathologists and local test planting of variously infected seedlings and apparently rot-free checks. Culling of seedlings with visible root rot may be necessary in stock offered for sale, or as a precaution against root infection in plantations.

Seedlings lightly infected with brown spot may be passed, but any with a third or more of the needle tissue involved in brown-spot infection may profitably be culled.

Ordinarily, tip-moth infested seedlings may be shipped if otherwise of plantable grade. Under certain circumstances already referred to, however, the injured seedlings should be either top-pruned or culled and the rest either dipped or sprayed.

Most nurserymen cull conspicuously chlorotic seedlings. On the hypothesis that chlorosis results from abnormalities in nutrition, this may be sound practice, although proof is lacking.

Seedlings that show traces of Sclerotium bataticola but are otherwise normal and vigorous probably need not be culled.

The best evidence available (pp. 329 to 331) indicates that, during the ordinarily safe planting season, southern pine seedlings should not be culled merely because their winter buds have elongated or opened.

Plainly marked specimens both of plantable seedlings and of seedlings culled because of low grade, rust infection, root rot, and various types of mechanical injury should be mounted on boards over the grading table to guide the crew.

Counting

The details and cost of grading and packing depend largely upon whether the seedlings are shipped in bulk or in small lots, and upon whether they are counted. Large companies producing their own stock usually ship in bulk, and base their cost accounts and control of planting upon the October nursery inventory. The U. S. Forest Service uses counts of sample bales to verify the fall inventory and to control bulk shipments of stock from one nursery unit to several different plantations. State forest nurserymen necessarily ship most of their stock in small lots, and have, until recently, felt obliged to count all the seedlings in each lot.

Bale counts.--In checking inventories and controlling shipments by bale count, a record is kept of the numbers of bales, species by species, for each shipment. Five percent of the bales in each shipment are selected at random and opened, the seedlings are counted, and the baling material and seedlings are returned to the baler to be repacked. Repacked bales are returned to the shipment from which they were drawn.

The sample bale counts for each shipment are averaged, and the total number of bales in the shipment is multiplied by the average number of trees per bale to get the total number of seedlings. The total number of seedlings is shown on the waybill accompanying the shipment. On the same document are shown, for each species: (a) the average number of trees per bale for all bales sent to that consignee that season, the current shipment included; (b) the total number of bales sent him to date; and (c) the total number of seedlings of that species sent him to date.

The nurseryman keeps copies of the waybills. By grouping them according to the nursery inventory units from which the stock was lifted, he can quickly compute the average number of seedlings per bale, the total number of bales, and the total number of plantable seedlings shipped from each unit. The last-named figure is an excellent check on the late-season inventory. If such a check is made on the first units lifted and shipped, the estimates for later units can be corrected fairly early in the planting season. Such corrections are sometimes of great practical help in administering shipment and planting. Frequently also, they lead to better understanding of various nursery injuries; the seriousness of southern fusiform rust in the nursery, for example, came to light in essentially this way.

Correct and careful sampling of either seedbeds or bales can give satisfactorily close estimates of the number of trees in lots of perhaps 100,000 or more. They are of no direct help, however, in filling orders for 1,000 to 20,000 trees apiece. Consignees receiving such small lots frequently check the counts, and sometimes keenly resent a shortage of 1 percent in a single container. State nurserymen therefore either count the trees shipped to fill such small orders, or include extra trees as a margin of safety.

Seedling counts.--General practice, when stock is counted exactly, is to tie loblolly, slash, and shortleaf seedlings in bundles of either 50 or 100 for later baling. Longleaf seedlings are tied 50 in a bundle. The bundles must be compact and firm enough to be handled rapidly, and the mass of roots must not be too thick for good contact with wet moss or moist ground during shipment or heeling-in. Bundles of all species except longleaf are tied with soft, rather thick cotton string just above the root collar, often by means of electric tying machines. The peciliar shape of longleaf seedlings necessitates tying by hand with two connected loops of soft string, one around the roots and one around the needles.

Hand-counting into 50- or 100-seedling bundles ordinarily is justifiable only in small or temporary nurseries or with experimental stock. Usually it is most efficient to make hand-counting and tying a separate operation following grading and culling. Except when percentages culled must be determined, only plantable seedlings are counted.

Where seedlings from large nurseries are shipped by count, grading, culling, root-pruning, and counting usually are carried out simultaneously on mechanical grading tables. Tables may be used to advantage for root-pruning and counting the graded stock even where fusiform-rust infection makes it impossible to grade and cull on them.

The grading tables are equipped with broad, moving belts, usually one on each side of the table, and running for 20 to 40 feet along the table top. Wooden strips bolted at right angles across each belt form "pockets" in each of which 5 seedlings may be placed. Workmen fill the pockets with plantable seedlings as the belt goes by, placing the root collars in line with marks on the belt or on the wooden cross strips. A revolving blade at the end of the table prunes the roots at a point 8 inches below the root collars, and a fine spray moistens the stock preparatory to packing. Gaps between sets of 20 pockets permit lots of 100 seedlings to be separated as they drop from the belt. Descriptions of grading and counting tables have been published (Robbins, 1942; Toumey and Korstian, 1942)(___, ___), and latest designs may be obtained from the Regional Forester, U. S. Forest Service, Atlanta, Georgia.

Once the counted seedlings have been tied in uniform bundles, orders are filled by counting out the requisite numbers of bundles. Summarizing the shipment totals gives the total nursery output, which is checked in some nurseries (Robbins, 1942)(___) by using recording electric tiers.

Counting by weight.--Moving averages of the weights of random 100- or 1,000-seedling samples from a particular lot of stock or of numbers of seedlings in random 10-pound samples, are used in some nurseries to fill 10,000- to 20,000-seedling orders by weight instead of by count. From 1 to 5 percent of extra seedlings, by weight, are added to each shipment as a margin of safety. With orders of these sizes, such weighing, even allowing for the extra trees added, is cheaper than counting. The method is reliable, however, only with fairly uniform stock.

Packing

Efficient packing of stock for shipment requires: (a) packing material that has a high moisture-retentive capacity and will keep the roots wet with minimum weight and bulk and permit storing packed seedlings for several days without injury; (b) light-weight wrappers or containers that will prevent moisture loss, stand rough handling, and, in shipments by mail or express, safeguard adjacent objects from wetting; (c) packing material and wrappers of low initial cost, and preferably capable of salvage and reuse; and (d) materials and equipment (including bale-binders) that will permit packing at high speed without injury to the trees and with a minimum of labor and of stops for repairs.

The favorite packing material in southern nurseries is sphagnum moss. Granulated peat and bagasse (shredded sugar-cane pomace) have also been used, apparently with good results. Sphagnum may be bought dry, in bales, from florists' supply houses or direct from producers; sometimes it can be collected locally from bogs. One 2- by 2- by 3-foot bale of dry moss will pack twenty to twenty-five 1,800-seedling bales of slash pine, and one 13- by 19- by 31-inch hamper of wet locally collected moss will pack approximately seven similar bales of shortleaf. Peat may be purchased from the same sources as sphagnum moss, and bagasse from some manufacturers of wallboard. Other packing materials have been described (Lunt, 1945; Newcomer, 1933; Toumey and Korstian, 1942; Wakeley, 1935)(___, ___, ___, ___), but their merits for packing southern pine stock do not seem to have been compared critically with those of sphagnum moss.

The U.S. Forest Service nurseries and several State nurseries pack southern pine seedlings in 60-pound bales each consisting of two 1- by 2- by 24-inch wooden slats, a 2- by 6-foot wrapper, two

metal straps, and enough moist sphagnum moss to separate and surround the layers of seedlings (fig. 26). Directions for baling are given on p. 564.

Figure 26.--Packing 60-pound bales of longleaf pine seedlings in paperlined burlap and wet sphagnum moss, in racks at end of mechanical grading table. A, bale built up and ready for completion of wrapping. B, tightening and fastening metal strap with hand-operated fastening machine. Note ends of wrapper rolled tightly around upper of two slats that stiffen the bale.

A 60-pound bale made as described holds 1,200 to 1,800 longleaf seedlings, and 1,500 to 3,000 seedlings of other southern pines. When the slats and wrappers were returned from the planting site to the nursery and used a second time, the material for such bales, at prewar prices, cost 4 to 8 cents per thousand trees, depending on the size of the stock. Sixty-pound bales are shipped 100 per 3-ton truck, making 120,000 to 250,000 or more seedlings per load.

Root Exposure, Nursery Storage, and Shipment

From the time the seedlings are first undercut by the lifter blade until they are planted, there is constant danger that the stock may be injured by exposure (especially of the roots) to sun and wind, by heating or drying during shipment or temporary storage, or by other causes, such as freezing. The principal safeguard against such injuries up to and during shipment is the nurseryman's skill and care in lifting, handling, and packing the stock.

The first source of danger comes when beds are undercut with the lifter several hours or days before the stock is removed from the soil. The danger is slight if the soil drops back into place behind the blade without cracking much or otherwise exposing the seedling roots or covering the tops. If the lifter seriously displaces the seedlings, they should be removed from the bed immediately.

Throughout lifting, grading, and packing, there is danger of weakening or killing the stock by exposing the tops and especially the roots to dry air, sun, and wind (pp. 338 to 339). Although southern pine nursery stock of all species stands exposure remarkably well, exposure is never beneficial and should be avoided to the greatest extent possible. Exposure of the roots (except to freezing) probably does negligible harm so long as the roots remain visibly moist. Lifting, grading, culling, counting, and packing southern pine nursery stock need not and usually does not expose the roots beyond the danger point.

Excessive drying of stock can be prevented by lifting and packing it or heeling it in promptly after undercutting the beds; by keeping seedlings out of the wind and sun and by covering the roots with canvas, wet burlap, or loose earth; and by dipping, spraying, or watering the seedlings at the first hint of drying of the roots. There is little evidence, however, that it does any good to rewet the roots after they have been dried by serious overexposure; such belated watering merely makes it more difficult to recognize injured seedlings by examination (Briggs, 1939)(___), and is questionable practice.

Since freezing of seedling roots may seriously reduce survival (p. 375), stock should not be handled bare-rooted in the open during freezing weather.

Heating of the stock in the bales, as a result of the physiological activity of the seedlings, is another source of danger. Packing in a cool, shady place, moistening the stock with cool water during packing, using bales that leave the seedling tops exposed, keeping the bales shaded and cool but exposed to gentle air movement, leaving bales in piles for as little time as possible, and watering the bales through their open ends, all reduce the danger of heating. In shipping by truck for more than 200 miles, it is U. S. Forest Service practice to unload the trucks once or twice en route and water the bales.

Although much southern pine nursery stock is delivered to the planters within 24 to 48 hours after it has been lifted, bad weather and other obstacles often require storage of a considerable percentage of the stock at the nursery for several days or even weeks. Any interruption to the lifting schedule may necessitate storage for at least a day before grading and packing. State nurseries frequently build up a two or three weeks' reserve of graded stock before starting shipment, lest bad weather prevent filling scheduled orders.

Southern pine seedlings can be stored for a week or more in U. S. Forest Service-type bales, with negligible harm, provided the bales are kept moist and are not allowed to heat (p. 336). In extreme cases, bales may keep seedlings in good condition for a month or six weeks, but success for such long periods is uncertain, especially toward the end of the lifting season. Storage in other forms of containers is not known to have been tested systematically.

The most common method of temporary storage in the nursery is by heeling-in. The technique is exactly like that for heeling-in at the planting site (p. 562), except that the cultivated nursery soil usually is better suited to the purpose than most soils at planting sites, and water is more readily available. The three essential precautions in heeling-in are that the layers of seedling roots be not more than 3 or 4 inches thick; that the soil come above the root

collars of all seedlings but not far up onto the foliage of any; and that roots and soil be kept continuously moist. Heeling-in overnight and for periods up to 10 days or 2 weeks causes little or no injury. Periods up to 4 weeks may have no ill effects, and may even improve survival (p. 338). Freezing weather apparently harms heeled-in stock less than it does freshly planted stock (p. 375).

Storage of southern pine nursery seedlings in still water, as in tubs, may kill them overnight (p. 337). Too few experiments have been made with cold storage of southern pine nursery stock to warrant recommendations concerning it.

GRADES OF NURSERY STOCK

The problem of satisfactorily defining southern pine seedling grades has proved to be complex. It is too important to be disregarded, but a thoroughly satisfactory solution cannot yet be given. The following discussion is limited to grades of 1-0 seedlings, since other classes of southern pine nursery stock are little used except in parts of the Central States (Chapman, A. G., 1936; Chapman, A. G., 1937; Chapman, A. G., 1948; Frederic, 1939)(___, ___, ___, ___). Grades, also, are considered apart from visible injuries caused by mechanical means, insects, or diseases.

The whole concept of nursery stock grades is based upon seedling capacities for survival and growth after planting. Nursery stock grades developed to date have attempted to judge these capacities by visible characteristics, including size. For convenience, since they depend upon morphology or external form, they are called morphological grades. But mere bigness or presumably desirable form of seedlings has not always assured plantation success. Too many plantations established under favorable conditions with seedlings of high morphological grade have survived poorly. Evidently the effects of non-visible characteristics within seedlings may be as important as the effects of size and external form. To distinguish them from morphological grades, non-visible, internal differences are termed physiological qualities.

Morphological Grades

The first systematic studies of southern pine nursery stock grades were begun with loblolly and slash pines in 1924-25, at Bogalusa, Louisiana, and were later extended to other species and areas. The seedlings were graded according to the presence or absence of secondary needles and of winter buds, the stiffness of the stems, the proportion of the stem having true bark, and the relative size of the seedlings as compared with the size of other seedlings in the same beds.

The specifications by which morphological grades were originally distinguished set no exact size limits between plantable and non-plantable seedlings, nor did they rigidly exclude seedlings without secondary needles from the plantable stock (Wakeley, 1935) (___). To standardize grading by large, inexperienced crews, to simplify supervision and inspection of grading, and to reduce disputes concerning grades of stock bought and sold, many agencies later established minimum root-collar diameter limits--and made the presence of secondary needles a rigid requirement--for all seedlings classified as plantable.

In their simplest form, present morphological grading rules specify that healthy, unbroken, 1-0 southern pine seedlings shall be culled if they lack secondary needles, if the root system is less than 5 inches long, or if the diameter at the root collar is less than 3/16 inch in longleaf pine or less than 1/8 inch in loblolly, slash, or shortleaf (table 20). For shortleaf pine in the Central States, Chapman (Chapman, A. G., 1948)(___) suggests somewhat different rules, requiring minimum stem diameters of 2/20 inch and minimum heights of 4 inches, and distinguishing higher grades by various ranges of heights for various diameters or ranges of diameters measured in 20ths of an inch at a point 1 inch above the ground. Top-root ratios, the calculation and publication of which was for many years popular among nursery investigators (Huberman, Ecology, 1940; Korstian and Baker, 1925; Show, 1924; Show, 1930; Wahlenberg, 1928; Wahlenberg, 1929; Wahlenberg, 1930; Wakeley, 1935)(___, ___, ___, ___, ___, ___, ___, ___), in addition to having certain theoretical weaknesses (Chapman, A. G., 1940; Roberts and Struckmeyer, 1946; Shirley and Meuli, 1939)(___, ___, ___), have never proved useful in grading southern pine nursery seedlings and have not been included in the grading rules.

The rules in table 20 have several excellent characteristics. Their use, although it requires close, alert observation, involves little personal judgment; they can therefore be enforced uniformly by nurserymen and foremen, and can be used with little dispute in buying and selling stock. They are simple to learn, and can be applied with the speed necessary in commercial lifting and packing. They can be applied directly, in advance of planting and without injuring the stock, to each and every seedling. They undeniably eliminate seedlings too small to plant and many seedlings too slender and weak-stemmed to plant with good chance of success. For application to southern pine nursery stock, they appear superior to any other rules so far developed.

Despite these advantages, however, neither the grading rules in table 20 nor morphological grades in general can be given an unqualified recommendation.

Success and Failure of Morphological Grades

During the first few years in which they were applied to southern pine seedlings, morphological grades seemed to work well. In the original studies of graded loblolly and slash pines at Bogalusa, for example, seedlings of the higher grades, during the first 5 years after planting, consistently survived and grew better than those of the lower grades; they also suffered somewhat less rabbit damage (Wakeley, 1935)(___). Because of their combined better survival and growth, the grade-2 seedlings in these studies produced 2.0 to 13.6 more cords of merchantable pulpwood per acre at 20 years, and the grade-1 seedlings produced 10.9 to 27.8 more cords, than did grade-3 seedlings (Wakeley, 1949)(___).

Table 20.--Specifications of morphological grades 1/ of uninjured 2/ 1-year-old southern pine seedlings

Grade	Usual heights 3/	Thickness of stem at ground	Nature of stem	Bark on stem	Needles	Winter buds
	Inches	Inches				
			LONGLEAF			
1	12 to 16	¼ to ½ or larger	...	...	Abundant. Almost all in 3's or 2's.	Usually present; usually with scales.
2	8 to 15; 6 to 8 if stem and buds are good	At least 3/16	...	...	Moderately abundant; at least part in 3's or 2's.	Buds with scales usually lacking; some without scales usually present.
3	Less than 8	Less than 3/16	...	...	Scanty; short; often none in 3's and 2's.	Not present.
			SLASH			
1	6 to 14	3/16 or larger	Stiff; woody.	Usually on entire stem.	Almost entirely in 3's and 2's.	Usually present.
2	5 to 8; sometimes 12	At least 1/8	Moderately stiff.	On lower part at least; often all over.	Part at least in 3's and 2's.	Occasionally present.
3	Usually less than 6	Less than 1/8	Weak; often juicy.	Often lacking.	Practically all single; usually bluish.	Almost never present.
			LOBLOLLY			
1	5 to 12	3/16 or larger	Stiff; woody.	Usually on entire stem.	Almost entirely in 3's.	Usually present.
2	4 to 7; sometimes 10	At least 1/8	Moderately stiff.	On lower part at least; often all over.	Part at least in 3's.	Occasionally present.
3	Usually less than 5	Less than 1/8	Weak; often juicy.	Often lacking.	Practically all single; usually bluish.	Almost never present.
			SHORTLEAF			
1	4 to 10	About 3/16	Stiff; woody. Usually a crook at ground level; often branching.	Usually on entire stem.	Almost entirely in 3's and 2's.	Usually present.
2	3 to 6; sometimes 8	About 1/8	Moderately stiff; often with crook and branches.	On lower part at least; often all over.	Part at least in 3's and 2's.	Occasionally present.
3	Usually less than 4	Distinctly less than 1/8	Weak; often juicy; often straight.	Often lacking.	Practically all single; bluish.	Practically never present.

1/ Grades 1 and 2 usually considered plantable, and grade 3 culled.

2/ Any seedlings with roots less than 5 inches long should be considered as grade 3 (culls), regardless of the quality of the tops.

3/ Needle lengths of longleaf pine seedlings; stem lengths of other 3 species.

As grades came into wider use, however, stock graded as plantable often failed to survive well even when planted carefully in favorable weather and on good sites. Such failures by no means proved that the grades were at fault; indeed, most people assumed that greater refinements of planting technique would end the trouble. The failures were common enough, however, to cause doubt concerning the reliability of the grades.

The survival pattern of the "untreated check" portions of numerous survival studies shows the doubt was well founded. From 1922 through 1941, the Southern Forest Experiment Station established 298 such untreated checks containing more than 57,000 seedlings, all graded as plantable. All had roots pruned to 6 to 8 inches; all were bar-planted on favorable sites, in favorable weather, during the regular planting season; and no lots were appreciably injured in any way during the year after planting.

From 1922-23 through 1926-27, the period during which morphological grades were coming into use, 38 of these untreated check plantings, involving the 4 principal southern pines, were made at Bogalusa, Louisiana. Among these there was a maximum range of only 26 percent in survival; the lowest survival was 72 percent.

During the 1934-35 through 1937-38 planting seasons, poor survival and some failures of graded stock were beginning to be reported throughout the South. In these 4 seasons, 48, 102, 18, and 43 check lots, respectively, were planted on the Johnson Tract, near Alexandria, Louisiana. The first 3 seasons the lots were equally divided between slash and longleaf; in 1937-38, a few lots of loblolly and shortleaf were included. All the stock came from one nursery, but from many widely separated and variously fertilized parts of its 50 acres. In 1934-35, survivals varied by 51 percent, with minimum survival 38 percent; the best and poorest lots were both slash pine. In 1935-36, when 102 lots were planted, survivals varied by 68 percent, with minimum survival 29 percent; the best and poorest lots were both longleaf pine. In 1936-37, when only 18 check lots were planted, survival again varied by 68 percent, with minimum survival only 28 percent; the best lot was slash and the poorest was longleaf pine. In 1937-38, survival varied by 37 percent, with minimum 63 percent; best and poorest survivals were both slash pine, but the survival of shortleaf pine, represented by only 8 lots, varied by 33 percent.

During the period 1938-39 through 1940-41, 49 untreated check lots were planted close to and in some cases among the previous outplantings on the Johnson Tract. The seedlings were drawn from the same nursery as those planted during the previous period, and were graded by the same rules, but had been grown on a limited area of uniform soil and uniformly favorable soil treatment, instead of at widely scattered points throughout the 50 acres. In marked contrast to the highly variable survivals in any one of the 4 previous years,

the total range in initial survivals of all 4 species in all 3 years of the later period was only 13 percent, and the lowest survival among the 49 lots was 87 percent.

Some Johnson Tract check lots of one or another species survived 91 to 100 percent in 1935-36, 1936-37, and 1937-38; some survived 89 percent in 1934-35. This makes it seem unlikely that better weather conditions caused the general improvement in survival during the period 1938-39 through 1940-41. It seems more likely that during the later period the capacity for survival (p. 274) of the seedlings in the check lots was uniformly high, and that during the earlier period, when the seedlings were being drawn from the entire nursery instead of from a limited area of uniformly good soil, the morphological grading rules failed to eliminate seedlings of low capacity for survival from a considerable number of the check lots. Similar failures of the grading rules to eliminate seedlings of low survival capacity seemed to explain, at least in part, the poor survivals in southern pine plantations in general during the middle and late thirties.

A number of new grading studies, established from 1934-35 onwards, caused further doubt about the ability of morphological grading rules to distinguish high capacity for survival. In these studies the grade-1 seedlings (table 20) generally made the best <u>growth</u>, as in the earlier studies at Bogalusa and elsewhere. In conspicuous contrast to the grade-1 seedlings in the earlier studies, however, the grade-1 stock in these later studies generally <u>survived</u> less well than the grade-2 stock, and sometimes less well than the grade-3 stock, which is ordinarily culled (unpublished report, Kisatchie National Forest, 1939; and unpublished data).

Slash pine stock planted on the Harrison Experimental Forest, in south Mississippi, in 1941, after grading in accordance with table 20, illustrates both the superior growth and the inferior survival characteristics of grade-1 stock in the later studies. Five years after planting, the survivals and average heights of these slash pines were: Grade 1, 29 percent and 14.4 feet; grade 2, 61 percent and 13.4 feet; grade 3, 53 percent and 11.0 feet. Here the seedlings of intermediate morphological grade clearly excelled those of highest grade in capacity for survival, and approached them in growth. Such superiority of medium-sized over large southern pine seedlings has been observed from Arkansas and Missouri to North Carolina at various times since the early thirties (Chapman, A. G., 1948; Claridge, 1933; Lynch, Davis, Roof, and Korstian, 1943; Meginnis, Jour. For., 1933)(___, ___, ___, ___), and medium-sized stock of other species has shown similar superiority (Bates, 1934; Paton, 1929; Wilde, "game food," 1946; Wilde, Nalbandov, and Yu, 1948; Wilde and Voigt, 1948)(___, ___, ___, ___, ___).

When nurserymen and planters realized that some trees classified as plantable actually had a poor chance of surviving, they began to suspect also that some of the stock culled might be capable of high survival. Their suspicions were strengthened when culls given away at a few nurseries were reported to have survived as well as or better than the seedlings sold as plantable.

The possibility that appreciable quantities of good stock were being culled raised a serious question. Culling part of a particular lot of seedlings increases the cost per thousand of those kept for planting; culling a large percentage may add exorbitantly to costs (fig. 27). Culling to meet the standards in table 20 usually adds at least 10 or 20 percent--sometimes much more--to any percentages culled for injury during lifting and for disease. If seedlings culled in accordance with table 20 are capable of good survival, culling them increases the total cost of planting without improving the results.

Figure 27.--Effect of degree of culling upon cost of seedlings kept.

It was suggested that the apparent failures of morphological grades from about 1935 onward might be the result of growing seedlings in much more uniform stands than were attainable at the time the grading rules were first developed. A second suggestion was that mechanical lifting had increased the breakage of lateral roots over that caused by hand-lifting. This was found to be true in some cases (pp. 334 to 335), but did not explain the high survival of seedlings classed as culls under the morphological grading rules. A third suggestion was that the rules given in table 20 specified the wrong root-collar diameters to differentiate plantable from cull stock. A fourth was that the morphological grades set forth in table 20 took insufficient account of variations in top dormancy and in the formation and opening of winter buds.

Critical Test of Morphological Grades

Whatever its cause, the apparent weakness of the morphological grades seemed serious enough to require special investigation. The last two suggestions in the preceding paragraph promised the most effective approach to the problem. In 1937-38 a study of longleaf grades and another of slash grades (fig. 28) were established on the Johnson Tract to see whether either the dimensions of the seedlings or variations in the apparent dormancy of their tops were causing inconsistencies in survival.

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Figure 28.--Representative samples of (A) longleaf pine seedlings and (B) slash pine seedlings planted in the 1937-38 grading studies on the Johnson Tract. Background lines are 3 cm. (1-3/16 in.) apart; for exact dimension limits of seedling subgrades, see figures 29 to 31.

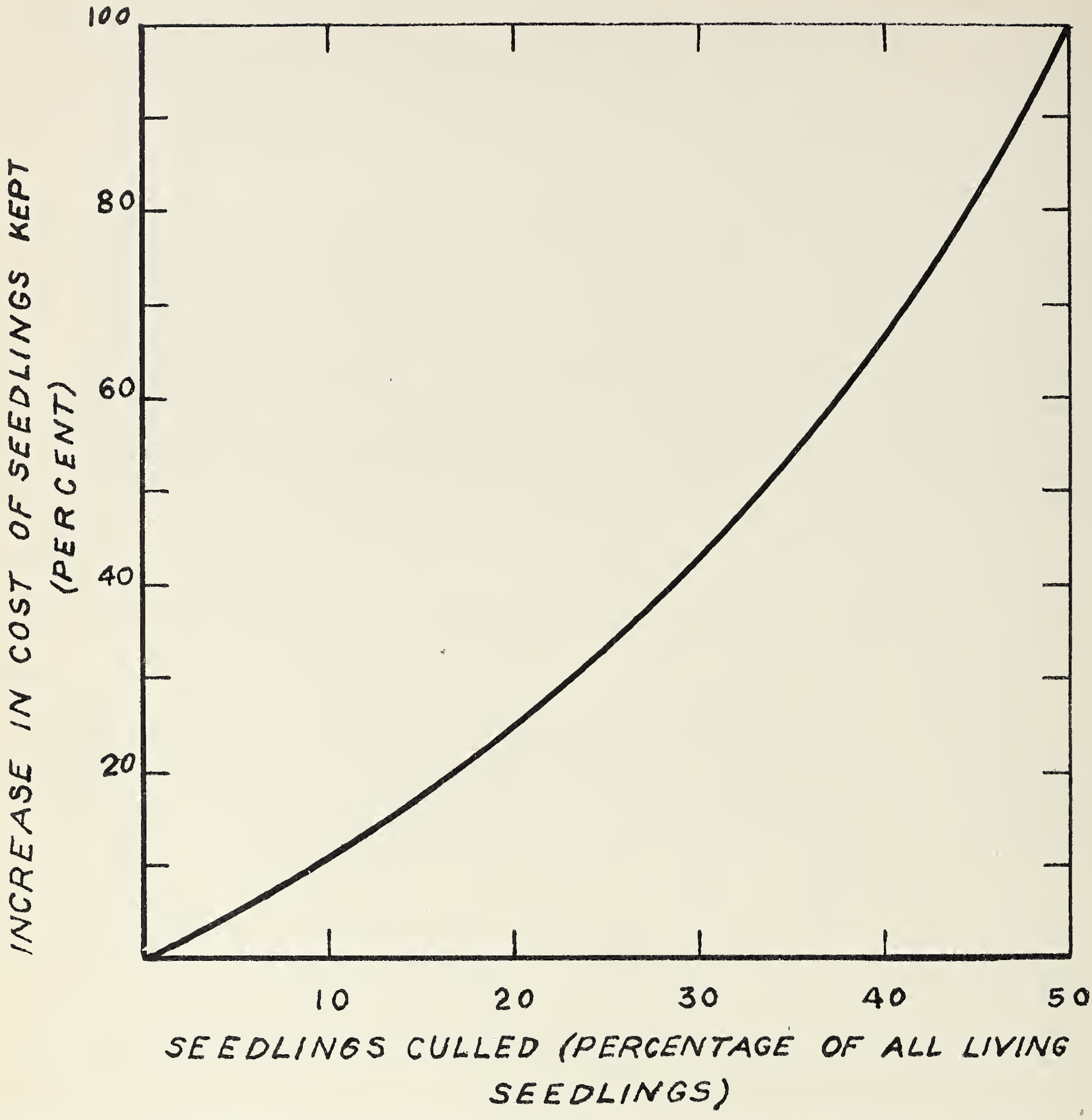


Figure 27.—Effect of degree of culling upon cost of seedlings kept.

In the longleaf study, the "plantable" and "cull" grades of table 20 were broken down into 8 subgrades distinguished by size and needle-development as specified in figure 29. In the slash study, the "plantable" and "cull" grades of table 20 were broken down into 12 subgrades distinguished by size, needle development, and apparent top dormancy, as specified in figures 30 and 31.

All the experimental planting stock for both studies was taken from one nursery. Stock of each species was drawn from each of two beds, alike in seed-source and date of sowing, but differing in seedling development. Within each species, the bed having a higher percentage of morphologically "plantable" seedlings and a generally more thrifty appearance was called Bed I, and the other, Bed II. The difference between the two slash pine beds was especially conspicuous.

Species by species, 100 seedlings of each subgrade were lifted from each of the two beds, and planted in balanced, randomized blocks to permit rigorous analysis of the results. The total numbers of seedlings planted were 1,600 longleaf and 2,400 slash. One well-qualified man graded all the stock.

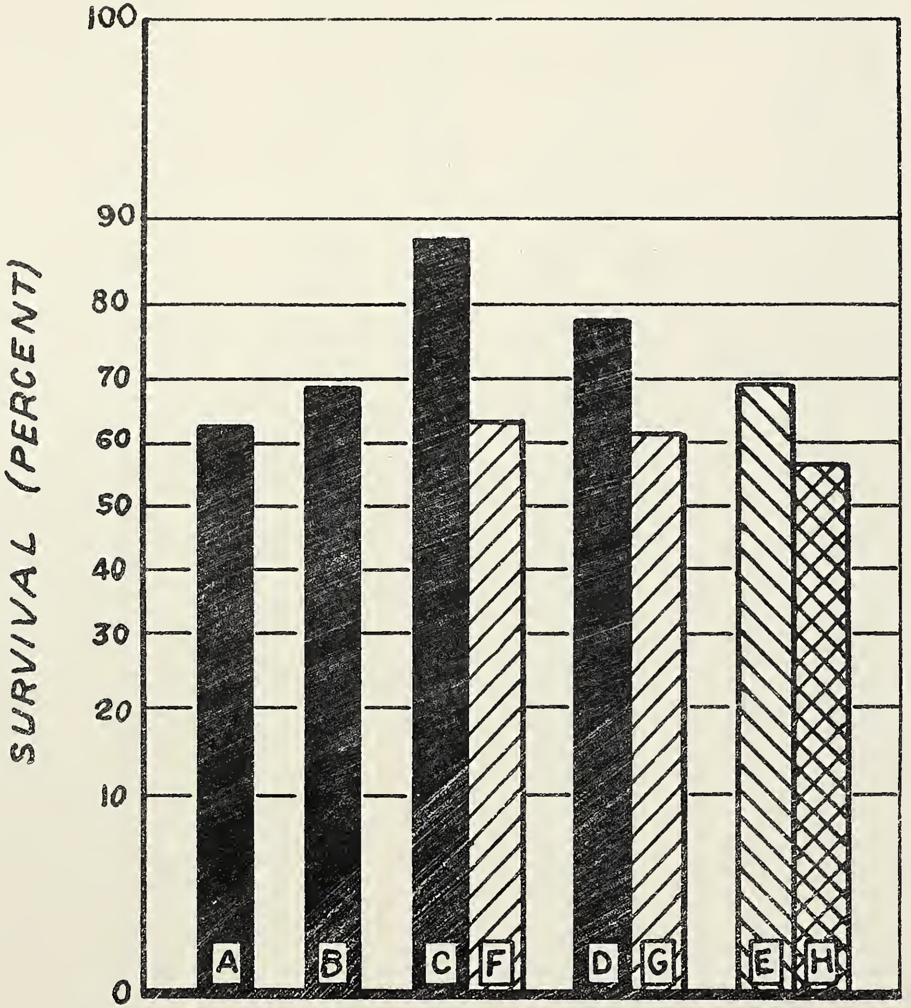
In the longleaf study the Bed I and Bed II stocks did not differ significantly in survival at the end of the first growing season in the plantation. Therefore they were averaged together, subgrade by subgrade, with the results shown in figure 29. There were conspicuous differences, several of them significant or very significant, in favor of subgrades with secondary needles as against those without, and particularly in favor of the intermediate as against the largest and smallest size classes. One of the longleaf subgrades that would commonly have been culled survived 6 percent better than the largest "plantable" seedlings, but this superiority was not statistically significant.

Figure 29.--Average survivals of longleaf pine seedlings from one nursery by morphological subgrades, Bed I and Bed II stocks combined, at end of first growing season after planting.

In the slash pine study the Bed II stock survived 88 percent, 86 percent, and 81 percent (average of all 12 subgrades combined) after 1, $2\frac{1}{2}$, and $8\frac{1}{2}$ growing seasons in the plantation, as against 71 percent, 64 percent, and 59 percent for Bed I stock. The differences in favor of the Bed II stock at the three successively later dates were therefore 17, 22, and 22 percent, all very significant.

Averaging the two slash pine stocks together, subgrade by subgrade as was done for longleaf, showed few important and no consistent differences in survival attributable to differences in apparent dormancy. It did show, as in longleaf, a clear superiority of intermediate over large sizes. It also showed that two "cull" subgrades survived significantly better than one or more other "cull" subgrades, and much too well (87 and 80 percent) to throw away (Wakeley, 1949)(___).

The most startling results appeared in comparing the 12 slash subgrades separately by Bed I and Bed II stocks (fig. 30). Here many of the larger differences are statistically significant. The economic



KEY

"Plantable"; large, with secondary needles

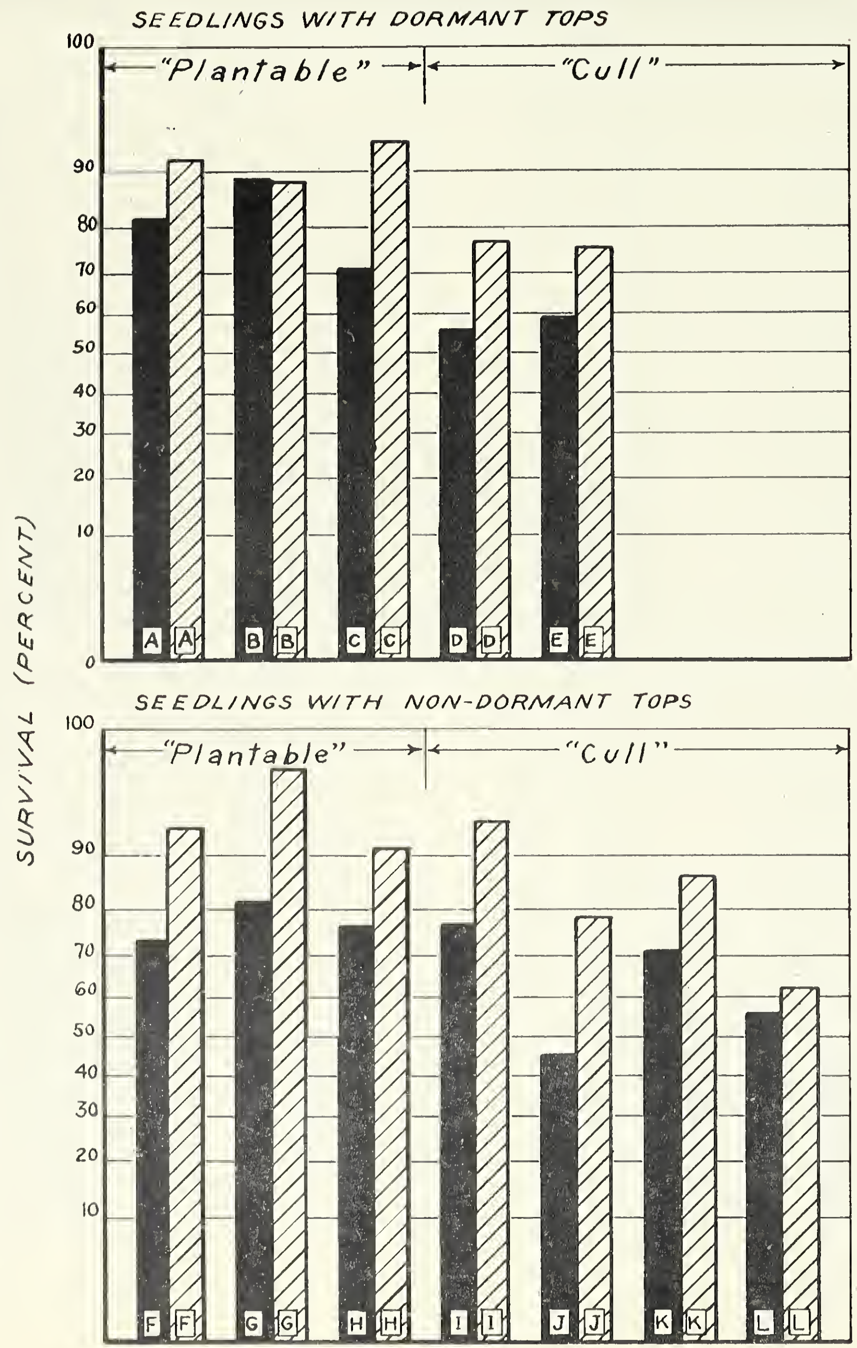
"Cull"; with secondary needles, but too small

"Cull"; large, but with no secondary needles

"Cull"; too small, no secondary needles

Sub-grade	Root-collar diameter (inches)
A	6/16 +
B	6/16 to 5/16
C, F	5/16 to 4/16
D, G	4/16 to 3/16
E, F	3/16 to 2/16

Figure 29.--Average survivals of longleaf pine seedlings from one nursery by morphological subgrades, Bed I and Bed II stocks combined, at end of first growing season after planting.



KEY

■ Stock from Bed I

▨ " " Bed II

Sub-grade	Root-collar diameter (inches)	Length of stem (inches)	Secondary needles
A, F	3/16 +	8 +	Present
B, G	3/16 to 1/8	8 to 5	"
C, H	" " "	5 -	"
D, I	1/8 -	8 to 5	"
E, J	" "	5 -	"
K	"Large"		Absent
L	"Small"		"

Figure 30.--Average survivals of slash pine seedlings from one nursery, separately by morphological subgrades and by Bed I and Bed II stocks, at end of first growing season after planting. Despite the higher percentage of "plantable " seedlings in the Bed I stock, and its more prepossessing appearance, the Bed II stock survived much better.

importance of the differences is obvious. With one exception out of 12 comparisons, the Bed II stock survived better, subgrade by subgrade, than the Bed I stock. In nine instances the Bed II excelled the Bed I subgrade in first-year survival by 15 percent or more. Furthermore, five of the six "cull" subgrades from Bed II survived better than two of the six "plantable" subgrades from Bed I; one of them survived better than the very best Bed I subgrade.

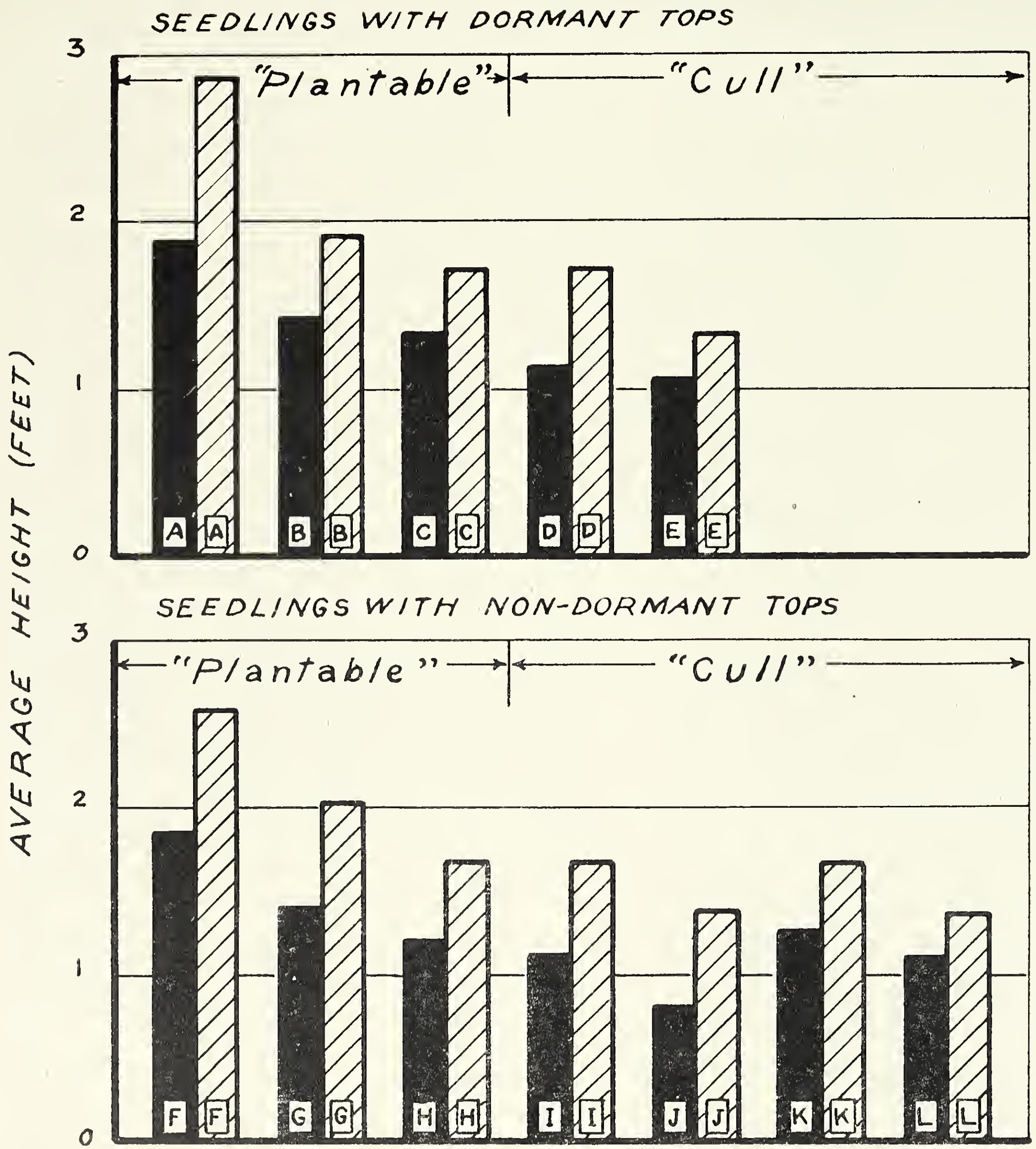
Figure 30.--Average survivals of slash pine seedlings from one nursery, separately by morphological subgrades and by Bed I and Bed II stocks, at end of first growing season after planting. Despite the higher percentage of "plantable" seedlings in the Bed I stock, and its more prepossessing appearance, the Bed II stock survived much better.

Reexamination $2\frac{1}{2}$ growing seasons after planting showed that these differences in survival in favor of the Bed II stock had increased. At this time, the average heights of the larger slash subgrades (unlike many of their survivals) generally excelled those of the smaller subgrades. Without exception, however, every slash subgrade from the Bed II stock had grown very significantly better than the corresponding subgrade from the Bed I stock, and all the Bed II "culls" had grown better than one or more of the Bed I "plantable" grades (fig. 31).

Figure 31.--Average heights of slash pine seedlings from one nursery, $2\frac{1}{2}$ growing seasons after planting, separately by morphological subgrades and by Bed I and Bed II stocks. Despite the higher percentage of "plantable" seedlings in the Bed I stock, and its more prepossessing appearance, the Bed II stock grew much better.

After $8\frac{1}{2}$ growing seasons in the plantation, the Bed II stock excelled the Bed I stock in height, subgrade by subgrade, and more conspicuously than ever. By this time the surviving Bed II stock, all subgrades combined, averaged 3.2 feet taller than the surviving Bed I stock. This is equivalent to an average height increase, in less than nine years, of 3/5 of a pulpwood bolt per tree, and on 37 percent more trees. Almost half of it was made by seedlings which, under a strict interpretation of the grading rules in table 20, would have been thrown away.

In the two studies described, the survivals and growth of the several subgrades within the generally accepted morphological grades showed that under the conditions of these particular studies:



KEY

Stock from Bed I

" " Bed II

Sub-grade	Root-collar diameter (inches)	Length of stem (inches)	Secondary needles
A, F	3/16 +	8 +	Present
B, G	3/16 to 1/8	8 to 5	"
C, H	" " "	5 -	"
D, I	1/8 -	8 to 5	"
E, I	" "	5 -	"
K	"Large"		Absent
L	"Small"		"

Figure 31.--Average heights of slash pine seedlings from one nursery, $2\frac{1}{2}$ growing seasons after planting, separately by morphological subgrades and by Bed I and Bed II stocks. Despite the higher percentage of "plantable" seedlings in the Bed I stock, and its more prepossessing appearance, the Bed II stock grew much better.

1. The root-collar diameter limits between "plantable" and "cull" seedlings in table 20 would result in the culling, because of size alone, of many longleaf and slash pine seedlings capable of high survival and good growth. (This confirmed the suspicions mentioned on p. 279.)

2. The apparent dormancy or non-dormancy of slash pine seedling tops had few significant and no very consistent effects on survival.

3. Although longleaf seedlings without secondary needles survived less well than those with secondary needles (fig. 29), many slash pine seedlings without them had excellent survival (fig. 30).

4. The largest seedlings of both slash and longleaf survived less well than those of intermediate size. (This confirmed the general observations and published studies cited on p. 278.)

5. Under the circumstances of the 1937-38 studies, the morphological grades were unreliable. The grading rules neither threw together seedlings of the same capacities for survival and growth, nor distinguished them with any certainty from those with different capacities, even within one bed. In the slash pine study the grading rules indicated the capacities of seedlings in two different beds so poorly that much the better lot of stock was considered the less plantable and thrifty (p. 281). It was concluded that similar failures of the same grading rules, applied to seedlings from the same nursery, might well have accounted for much of the variability in survival of the check lots (p. 277) planted on the Johnson Tract during 1934-35 through 1937-38. If so, such failures might also have accounted for much variability in survival of stock from other nurseries.

Physiological Qualities

The 1937-38 grading studies demonstrated one other fact of more general and far-reaching importance than the five discussed in the preceding paragraphs. They showed conclusively that the physiological qualities of seedlings (p. 274) can overbalance the effects of their morphological grades upon survival and growth.

The fact that physiological qualities differentiate internal seedling conditions must be emphasized. Physiological quality cannot be determined by ocular inspection. No means such as chemical testing of the foliage (Wilde, Nalbandov, and Yu, 1948; Wilde and Voigt, 1948)(___, ___) has yet been developed for recognizing various physiological qualities of southern pine nursery seedlings in advance of planting; the only way so far discovered for determining them is to plant the seedlings and observe their survival and growth. For

these reasons, physiological quality classes resembling the morphological grading rules in table 20 have not yet been formulated. Even when they shall have been, it is unlikely that they will be applicable to individual seedlings. They probably will have to be confined to determining the average physiological quality of large lots of stock, by a process of sampling, much as average germination percent is determined for large lots of seed.

These facts do not lessen in the least the importance of physiological quality. They merely make it more difficult than one would wish to use physiological quality classes as guides to nursery and planting practice. Recognition of the existence and importance of physiological quality has been generally helpful in correcting misconceptions concerning morphological grades and in learning the causes of high and low initial survivals. The fact that the physiological quality of specific lots of stock can be determined from behavior in the plantation has been of immense practical help in specific cases by showing which nursery treatments produce high quality stock.

The known facts and more important surmises concerning physiological qualities of southern pine nursery stock may be summarized as follows:

1. Physiological quality is not necessarily identical with capacity to survive and grow. For example, of two seedlings having equally high physiological quality, the larger might be better able to resist frost-heaving or to compete with overtopping grass, and therefore have a higher capacity to survive. In the great majority of cases, however, physiological quality and the capacity to survive and grow probably are about the same for all practical purposes.

2. Morphological grades and physiological qualities may or may not coincide. It is thought that coincidence of morphological grade with physiological quality explains the many good survivals of seedlings of high morphological grade, and the many poor survivals of those of low morphological grade. Lack of such coincidence is believed to explain equally well many reported cases of poor survival of morphologically high-grade stock and of good survival of morphologically low-grade stock.

3. High physiological quality of southern pine seedlings seems to improve survival principally by insuring that the water intake of the seedlings immediately after planting equals or exceeds their water loss. It seems highly probable that in many cases they insure this favorable water balance by enabling the seedlings to extend new root tissue into the soil of the planting site within the first few days after planting. These two surmises are supported by the observed reactions of seedlings to freezing and to drought (pp. 321 to 322, and 375 to 376); by the behavior of many thousand variously treated and planted seedlings in survival studies (pp. 323 to 356); and by

observations and measurements of new roots formed by seedlings during the first few weeks after planting. In particular, experimental treatments that have most consistently reduced the physiological quality of longleaf and slash pine seedlings--without in any way affecting their morphological grade--have also interfered most seriously, and very significantly, with the prompt formation of new roots after planting (unpublished data). The importance of favorable water balance to initial survival, of new root growth to water balance, and of physiological condition of the stock to both, is too well substantiated by published studies of southern pines and other species to require elaboration here (Addoms, 1946; Brener and Wilde, 1941; Chapman, A.G., 1940; Daubenmire by Pearson, 1943; Erickson and Smith, 1947; Kelley, Hunter, and Hobbs, 1945; Kopitke, 1941; Kozlowski and Scholtes, 1948; Kramer, 1946; Kramer and Coile, 1940; LeBarron, Fox, and Blythe, 1938; Lynch, Davis, Roof, and Korstian, 1943; Maki and Marshall, 1945; Marshall, 1931; Marshall by Shirley, 1931; Meyer, 1928; Pearson, 1934; Rosendahl and Korstian, 1945; Schopmeyer, 1939; Schopmeyer, 1940; Shirley, 1945; Shirley by Baker, 1945; Shirley and Meuli, 1938; Shirley and Meuli, 1939; Wilde, 1946; Wilde, Nalbandov, and Yu, 1948; Wilde and Voigt, 1948; Wilde, Wittenkamp, Stone, and Galloway, 1940)(___, ___).

4. Mineral nutrition, which is governed largely by the natural fertility level or the fertilizer treatment of the nursery soil, may greatly affect the physiological quality of southern pine nursery stock. Although differences in climatic conditions may also play a part, differences in mineral nutrition probably are the principal causes of differences in survival among lots of stock produced in different nurseries but graded by the same morphological grading rules and planted at the same time on the same site. Records of a number of such matched plantings of stock from different nurseries show that seedlings from some nurseries tend to survive well and those from others to survive poorly, regardless of season or planting site, or even of species (table 21). Differences attributable to nursery source alone, and probably largely to differences in mineral nutrition, may make the difference between success and failure in the plantation. More recent studies have shown very significant differences in survival of morphologically similar southern pine seedlings, arising from the use of different inorganic fertilizers under controlled conditions in the same nursery (unpublished data). The references cited in the preceding paragraph also include examples of the effects of mineral nutrition on the physiological condition and consequent survival of southern pine and other seedlings.

5. Variations in stored food reserves seem to be another important source of variation in the physiological quality of southern pine seedlings. Stored food reserves may affect water intake and outgo directly, and may affect water intake indirectly through their effect on the development of new root tissue after planting. Even during a

Table 21.--Varied survival of graded 1/ southern pine seedlings grown in different nurseries and planted on comparable sites within seasons

Season and location in which planted	A	B	C	D	E	F	G	H	I	J	K	L	M	N
	Percent													
Slash Pine														
1936-37, Alabama	...	...	...	...	...	...	94	...	39	...	...	...	...	...
1938-39, Mississippi	98	96	...	80	...	...	93	...	96	57	66	...	...	38
1939-40, Mississippi	...	...	...	...	76	...	58	...	54	...	50	...	58	...
1939-40, Florida	...	...	...	...	66	...	24	...	38	...	36	...	27	...
1939-40, Louisiana	...	...	...	...	92	...	86	...	77	...	74	...	70	...
1940-41, Alabama	...	...	...	...	...	61	64	76	83	...	...	48	...	49
Longleaf Pine														
1936-37, Alabama	...	...	3/ 85	...	...	...	...	...	20	...	...	...	...	...
1940-41, Alabama	...	...	...	...	...	90	93	70	69	...	...	57	...	62

1/ All plantable according to table 20, except as noted.

2/ Nurseries arranged in descending order of average survival for all seasons and locations.

3/ Mostly culls according to table 20.

5-weeks period in midwinter, accumulation of such food reserves may be both extensive and highly variable (table 18). Experimental interference with such accumulation of stored food reserves by shading seedlings heavily for 10 to 12 weeks before planting has reduced the survival of longleaf pine seedlings by 15 to 26 percent, and of slash pine seedlings by 56 to 79 percent, as compared with the survivals of unshaded checks. In one study the mortality of the shaded seedlings of both species was clearly associated with their failure to develop new roots as promptly after planting as did the unshaded seedlings. The importance of stored food reserves in connection with frost hardiness and other physiological conditions has also been shown in a number of studies of other species (Chapman, A. G., 1940; Kopitke, 1941; Meyer, 1928; Pearson, 1934; Shirley, 1945; Shirley by Baker, 1945) (___, ___, ___, ___, ___, ___).

6. The relative difficulty with which plants obtain an abundance of moisture from the soil is referred to as the "water tension" under which they are grown. Although the subject has not been investigated systematically in southern pine seedbeds, it seems probable that water tension, particularly toward the end of the nursery growing season, greatly affects the physiological quality of the seedlings. High water tension--that is, regular or periodic exposure to conditions approaching drought, but not extreme enough to cause injury--has, with several species of conifers and other plants, increased stored food reserves, increased drought resistance, and very greatly increased survival after planting (Chapman, A. G., 1944; Eaton and Ergle, 1948; Erickson and Smith, 1947; Kelley, Hunter, and Hobbs, 1945; Marshall, 1931; Marshall by Shirley, 1931; Schopmeyer, 1939; Schopmeyer, 1940; Shirley and Meuli, 1939)(___, ___, ___, ___, ___, ___, ___, ___, ___). Higher water tension in the equally well watered but more excessively drained soil of Bed II may have been the main reason for the better survival of the Bed II than of the Bed I slash pine stock in the studies described on pp. 285 to 286. Presumably, also, it explains the effectiveness of withholding water in the fall and late summer to "harden off" the stock, as recommended on p. 223.

7. The physiological qualities induced in southern pine nursery seedlings by mineral nutrition, etc., may be modified by the physiological effects of sprays applied at lifting time--favorably in the case of some sprays, unfavorably in the case of others (p. 343). Bordeaux mixture (both alone and with various stickers), stickers without Bordeaux, and at least two rabbit repellents have produced significant variations in the survival of southern pines in this manner, entirely aside from the fungicidal or repellent effects of the sprays (unpublished data). Similar effects of sprays have been reported for other species of pine (Marshall and Maki, 1946; Shirley and Meuli, 1938)(___, ___).

Recommendations

The fact that various morphological grades and physiological qualities both occur within the same lot of stock, together with the inconsistent results obtained from the first and the lack of definite knowledge about the second, makes it difficult to write specific recommendations for grading southern pine nursery seedlings. Nevertheless the following seem justified in the light of available information.

1. Regardless of morphological grades or physiological qualities, cull all seedlings infested with scale insects, infected with rust, or conspicuously infected with root rot, or with broken or conspicuously skinned stems, badly stripped, skinned, or split roots, total root lengths of less than 5 inches, or conspicuously stripped foliage. (This is culling based on sanitation and breakage rather than on grades, but there is strong evidence to support it, and it sets the stage, so to speak, for grading.) Individual longleaf seedlings with 35 percent or more of their total leaf area in brown-spot lesions or dead tips should be culled also when found. Seedlings should not be culled solely because of infestation by Nantucket tipmoth, except to safeguard uninfested planting sites.

2. Where seedling densities have not been well controlled, and exceed 60 living seedlings per square foot in considerable patches or throughout the beds, use the morphological grading rules of table 20. With seedlings grown in over-dense or irregular stands, these rules effectively eliminate seedlings too small and weak to plant easily, and in the larger-sized seedlings appear to differentiate capacities to survive and grow.

3. Where seedling densities are uniformly below 60 living seedlings per square foot, and especially where soil management has been fairly good and stock from the same nursery has previously survived well on ordinary sites, two courses of action are open.

a. When the producer of the stock is planting it on his own land, the grading rules of table 20 may be disregarded and bed-run seedlings may be planted, except for culls--the infested, infected, and mechanically injured seedlings and seedlings too small to plant conveniently. (Seedlings less than 3 inches high are definitely too small for easy commercial planting.) If desired, such bed-run stock may be planted at slightly closer spacing than usual, to offset slightly higher mortality.

b. When the stock from such beds is being sold, some grading in addition to culling usually is necessary to insure justice to the buyer, and to avoid disputes. (There may be an exception when stock from the nursery in question has demonstrated beyond any doubt the ability to survive exceptionally well regardless of size.) Grading of stock to be sold may take the specifications of p.275 and table 20 as a starting point. Unless experience has shown physiological

quality to be low, however, these grades may be relaxed somewhat. Seedlings without secondary needles but above the minimum size limits, and seedlings slightly below the minimum size limits but with good secondary needles, may be shipped as plantable. From December 1 through February 15, evidences of non-dormancy of tops may be disregarded. Such modifications of the grading rules should be made clear to the purchaser, however, and should be supported to the extent possible by plantation performance records of borderline classes.

4. Stock for especially severe sites or for particularly exacting customers should be supplied, so far as possible, from beds or compartments known from past experience to produce seedlings of high physiological quality. If there is no information concerning physiological quality from different parts of the nursery, remember that morphological culls (grade 3, table 20), the largest morphological grades (grade 1, table 20), and seedlings with obviously non-dormant tops have all, on one occasion or another, survived less well than apparently top-dormant seedlings of intermediate "plantable" size (grade 2, table 20) from the same beds; and grade accordingly.

5. So far as possible, test and confirm the effects of changes in nursery practice upon physiological quality, by planting and re-examining representative samples of stock grown under both old and new practices. Testing of physiological quality, even by such a slow method, is a far sounder guide to nursery practice than is the recording of changes in morphological grade following changes in treatment.

NURSERY SOIL MANAGEMENT

Good nursery soil management is an essential step in growing the southern pines for planting. It justifies considerable expenditure. Southern pine seedlings are an outstandingly valuable crop, regularly worth at least $3,000 to $5,000 per nursery acre to produce 37/. One must expect to apply an appreciable percentage of these

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37/ The approximate average prices received per acre from some other southern crops in 1947 were: Louisiana sugar cane, $113; Louisiana cotton, $118; Louisiana strawberries, $376; North Carolina tobacco, $481; Kentucky tobacco, $505 (U. S. Department of Agriculture, 1949) (___).

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amounts to soil fertility maintenance, or see the quality of the stock go down.

Though there is an immense amount of complex information on soils and soil management, its adaptation to nursery soil management has barely begun. Research on southern pine nursery soils has been fragmentary, largely empirical, and too seldom followed through into the plantation. Soil differences from nursery to nursery frequently make findings in one place inapplicable in another; Auten (Auten, Jour. Agr. Res., 1945)(___) has reported a striking example. All that can be done here is to call attention to the more important southern nursery soil management problems recognized to date, and give some general rules and specific suggestions for dealing with them. The individual nurseryman should be quick to challenge either rules or suggestions in the light of clear contrary evidence from his own nursery.

Seedling Requirements

Adequate mineral nutrients alone will not insure good nursery seedlings. Good physical structure and condition of the soil are essential to optimum germination, emergence, root development, and seedling moisture relations (Andrews, 1941; Auten, Jour. Agr. Res., 1945; Lenhart, 1934; Muntz, 1944)(___, ___, ___, ___). They are also essential to good erosion control and drainage, and to maximum ease, flexibility, and economy of bed making and particularly of lifting. Not only disease and low nutrient levels but also poor physical condition of the soil should be suspected and investigated whenever stock fails to develop uniformly and well.

Although pines, and particularly the principal southern pines, are among the least exacting of forest trees in their requirements for mineral nutrients (Lutz and Chandler, 1946; Pessin, 1937; Wahlenberg, 1946; Wilde, 1946)(___, ___, ___, ___), they must have relatively large

amounts of nitrogen, phosphorus, potassium, and calcium, smaller amounts of sulfur and iron, and traces of magnesium, boron, copper, manganese, zinc, and other elements. For southern pine nursery seedlings to attain high physiological quality, these elements apparently must be available in nearly optimum proportions one to another; Wilde and coworkers have similarly emphasized the need for optimum nutrient levels by nursery stock of northern species (Wilde, Wittenkamp, Stone, and Galloway, 1940)(___). Moreover, the great number of southern pine seedlings produced per acre (usually about one million) makes the total nutrient requirement <u>per acre of nursery soil</u> fairly high.

Moderate acidity (pH 6.0 to 5.0) seems about optimum for southern pine nursery soils, although acceptable results have been obtained on soils as strongly acid as pH 4.5. Soil acidity or alkalinity is expressed in terms of the pH, or hydrogen ion concentration, according to a numerical scale in which 7.0 represents neutrality (neither acid nor alkaline), and 3.0 represents about the extreme acidity tolerated by southern pine trees. A pH of 8.0 represents moderate alkalinity, ordinarily not favorable to southern pines and apparently quite injurious to young southern pine seedlings. Levels of soil acidity differing little in their direct effects on pine seedlings may, however, differ greatly in their effects on the availability of one or another nutrient element the seedlings must get from the soil (p. 299), and on damping-off (pp. 248 to 252).

Effects of Cropping System on Soil

The prevailing system of producing southern pine nursery stock was developed primarily for economical sowing of the seed and watering, weeding, and lifting of the seedlings. It is hard on most soils in the southern pine types.

Suitable location and the requirements of seedlings for drainage, soil texture, and hydrogen ion concentration (p. 207) often limit choice of nursery site to soils structurally subject to severe erosion and low in mineral nutrients--particularly nitrogen and phosphorus (Andrews, 1947; Lutz and Chandler, 1946; Mehring, 1945; Richardson, 1945)(___, ___, ___, ___)(unpublished data, U. S. Forest Service)--and sometimes to soils so acid as to make essential mineral nutrients relatively unavailable to the plants (Auten, Jour. Agr. Res., 1945; Chadwick, "Reaction", 1946; Richardson, 1945)(___, ___, ___). Organic matter usually is low, and, under prevailing nursery practices, is likely to be reduced (Auten, Jour. Agr. Res., 1945; Slavin, 1947; Thompson and Smith, 1947)(___, ___, ___)(unpublished data, U. S. Forest Service). The coarser soils may retain moisture poorly or lack desirable cation-exchange capacity.

On many sites, the deep plowing required for good root development and the deep undercutting unavoidable in mechanical lifting dilute the surface soil with poorer subsoil. Terracing to control erosion and grading to improve drainage are likely to increase such damage.

Unavoidable foot and machine traffic packs the soil injuriously. Often, especially during lifting, the soil must be worked when it is undesirably wet. The nursery schedule almost invariably exposes the soil to packing by rain and to erosion by both rain and wind for considerable periods each year, and to full sunlight at times when high temperatures accelerate loss of desirable organic matter through oxidation. The open winters, heavy rainfall, and hot summers characteristic of most southern pine nurseries intensify injuries to the soil from these various causes.

Typical crops of southern pine nursery stock, like those of northern nursery stock (Wilde, 1946)(___), take more mineral nutrients out of the soil than do field crops--perhaps four to six times as much as cotton or corn. The heavy drain results partly from the sheer mass of plant tissue produced by the closely spaced seedlings, and partly from their exceptionally complete removal from the soil. The copious artificial watering required by southern pine seedlings may leach additional percentages of nutrients out of some nursery soils.

Supplying nutrients in the form of inorganic ("commercial") fertilizers often reduces soil organic matter and injures soil structure. Wrong choice of fertilizer may affect soil acidity adversely.

In short, unless their effects on the soil are taken into account, the techniques used in growing nursery stock may make the soil progressively less capable of producing it.

Keeping the Soil in Good Physical Condition

Achieving and maintaining good physical condition of the soil usually requires systematic efforts to increase organic matter content (pp. 301 and 304); to protect the soil surface as continously as possible with mulches (p. 219), cover crops (p. 304), or seedling stands (p. 222); to minimize movement of water over the surface; to avoid exposure of subsoil and intermingling of subsoil with surface soil; and to avoid packing the soil or working it when it is very wet.

Increasing the organic matter content, in addition to directly improving soil structure, increases its water-absorptive capacity. Combined with protection of the soil surface, it does much to decrease erosion by surface water. Where rainfall is heavy, however, and slopes exceed 2 or 3 percent, terracing usually is necessary to control sheet erosion, even though the terraces expose some subsoil or mix it with surface soil.

Soil cropping, bed making, and lifting should be done with the minimum possible amount of driving or walking on the beds. Although moderate firming of seedbed soil by rolling (p. 212) seems harmless or even beneficial, heavier packing is injurious to most soils (Slavin, 1947)(___). In some southern pine nursery beds, corners repeatedly

cut across by trucks at lifting time, and also ruts of dirt roads that crossed the site before the beds were first established, have remained unproductive even after years of subsequent cultivation and fertilization. Foot traffic and heavy machinery inevitably pack the soil severely in nursery paths. Where beds have been moved, the portions of them falling on former paths usually show poor growth and heavy mortality. The movement of soil from paths into beds by plowing and harrowing between seedling crops may account for some otherwise unexplained fail spots in later seedling stands.

Plowing, disking, or undercutting any but the most sandy soils when they are very wet is likely to injure their structure. Some undercutting of wet soils is unavoidable, but should be kept to a minimum, and the harm done should be reduced by maintaining soil organic content at the highest possible level.

Fertilizing and Amending Nursery Soils

Effective fertilization or amendment involves finding out what the soil lacks and learning how to supply it without injury to soil or seedlings. Choice of treatment requires fairly accurate judgment concerning the physical condition, nutrient level, pH concentration, and organic matter content of the soil, and knowledge of how these are likely to be affected by different treatments. An amount of an inorganic fertilizer effective on one soil, for example, may be inadequate on a second soil, and highly injurious to seedlings on a third. Green manure crops may improve organic content primarily, or modify it and nutrient levels about equally. Most soil amendments are applied to improve organic content, but some may seriously upset nutrient balance unless inorganic fertilizers are applied with them. Time, amount, and method of application must often be chosen as carefully as kind of treatment, to avoid waste of material or injury to seedlings.

Poor water absorption, poor water retention, poor moisture-supplying capacity, high erodibility, and a tendency to form a surface crust or bake hard when dry are signs of poor physical condition. They are observable in the soil itself or in the stunted growth, poor root development, and sometimes in the wilting, of the seedlings. Poor physical condition is likely to be associated with percentages of fine particles less than 15 or more than 25 percent by weight (p. 207) and with soil organic matter below 1.0 percent, and may often be corrected by increasing organic matter to 1.5 or 2.0 percent.

Hydrogen ion concentration can be measured closely enough for all practical purposes by means of inexpensive test kits (Wilde, 1934) (___). In general, soils less acid than 6.0 may require fertilizers having an acidifying effect, while in those more acid than 5.0 much of the phosphorus already present or added as fertilizer will be unavailable to seedlings unless acidity is reduced (p. 299).

Fairly accurate direct measurements of organic matter content may be made by the ignition test or (Wilde, 1946)(___) other techniques. Ignition-test readings will be high if the soil contains charcoal. Soil organic matter content determinations usually can be made most easily by the State agricultural experiment station.

Foliar analyses, which have proved useful guides to the fertilization of fruit and other crops (Tukey, 1946)(___), have not yet been adapted specifically to southern pine nursery stock, and chemical analyses of the soil usually are difficult to translate into exact guides to nursery fertilization. The State agricultural experiment station may nevertheless be able to tell, from adequate random samples, whether the nutrient elements in the nursery soil are sufficient for agricultural crops, or dangerously low. Moderate to large quantities of the various elements should be added accordingly to allow for the somewhat greater demand of pine seedlings than of ordinary agricultural crops (p. 295).

When soils analyses are not available it is generally safe to assume that nitrogen and phosphorus are most likely to be deficient, and potassium next most likely. As a rule, southern pine nursery soils contain ample calcium, sulfur, iron, and trace elements, and the calcium and sulfur already present are augmented whenever phosphorus is applied in the form of superphospate. The necessity of applying lime before sowing pine, either to supply calcium or for other purposes, seems never to have been demonstrated in any southern nursery, and liming may seriously increase damping-off (pp. 248 to 252).

The appearance of the seedlings themselves gives many clues to desirable fertilizer treatments (Collings, 1947; Wilde, 1946)(___, ___). Chlorosis (p. 257) may indicate overdoses of readily soluble inorganic fertilizers, lack of iron (remedied by foliage sprays), or nitrogen deficiency. Stunting and yellowing often indicate nitrogen deficiency. Irregular growth, poor root development, and purpling before cold weather are likely to mean phosphorus deficiency (p. 236). Sudden death of very young seedlings as the soil dries but before drought conditions develop, or dying and browning of needle tips, or visible chemical injury to roots, occurring on fertilized beds when stock remains healthy on unfertilized beds, usually means fertilizer has been applied in excess or in too easily soluble form. Eliason has published an ingenious method of testing the relative nitrogen deficiency on variously fertilized or cropped seedbed areas by sowing buckwheat, which is a sensitive indicator of nitrogen shortage (Eliason, 1935)(___).

Pending the development of the best fertilization or soil amendment for particular nurseries, overtreatment can be avoided by making moderate applications, perhaps short of optimum, but large enough to do some good. It is easier to add more nutrients later than to correct an initial overdose (Wilde, 1946)(___).

Locally effective soil management practices can be learned most rapidly and reliably by laying out a series of small test plots each year in representative parts of the nursery to try, in advance of general application, the fertilizers and soil amendments which appear to be desirable. Tests will be most valuable if each treatment is tried in at least two separate plots to see whether it gives consistent results; if detailed records of treatments (including dates and rates) and results (survival, growth, damping-off, weed-development, and pH concentration) are kept; and if treated seedlings and untreated checks are out-planted and reexamined in the field. Small plots may also be sown before the main crop in the spring to see whether proposed fertilizer treatments cause excessive emergence failures, damping-off, or root injury or foliage "burning" of very young seedlings. In evaluating such advance sowings, however, the possible effects of season of sowing on damping-off must be allowed for (p. 251) and outplanting may be omitted.

Inorganic Fertilizers

The simplest means of adding known amounts of mineral nutrients to nursery soils, and often the only economical way of correcting serious nutrient deficiencies, is by applying inorganic fertilizers. Examples of their negative or harmful effects and sweeping recommendations against their use (Auten, Jour. Agr. Res., 1945; Chadwick, "Reaction", 1946; Davis, Wright, and Hartley, 1942; Lynch, Davis, Roof, and Korstian, 1943; Toumey and Korstian, 1942; Wakeley, 1935)(___, ___, ___, ___, ___, ___) must be discounted somewhat because of the important need such fertilizers fill in nursery soil management. Such failures as occur probably are attributable not to the fact that the fertilizers are inorganic, but to incorrect application for the particular seedling species, seedling age, rainfall, watering, soil fertility level, soil texture, cation-exchange capacity, or soil acidity involved.

The mineral nutrient requirements and tolerances of southern pine seedlings, like those of other conifer seedlings, differ at different ages. Very young shortleaf pine seedlings are more sensitive to excess calcium than are older trees (Chapman, A. G., 1941)(___). Nutrient concentrations optimum at mid-summer or near lifting time may be injuriously high for seedlings in the cotyledon stage (Mitchell by Shirley, 1939)(___). These variations in requirements with age may make it desirable, in fertilizing before sowing, to use the less soluble rather than the more easily soluble fertilizers. The "carrier", or chemical compound, in which a nutrient is applied may also affect the extent of injury to seedlings (Skinner, Nelson, and Whittaker, 1945; Wilde, 1946)(___, ___).

The amounts of the various nutrient elements that must be added to the soil to meet the requirements of specific seedlings may vary enormously from nursery to nursery, soil to soil, and year to year.

They depend not only on the apparent shortages of the necessary elements as shown by soil analyses, but also on soil texture, leaching, chemical reactions within the soil, and potential drain by seedlings and other plants.

Soils high in silt and clay require larger applications of a given element to produce a given result than do soils low in these components (Wilde, 1935)(___).

Some of any element added as fertilizer may leach out before the plants can use it. Nutrient elements vary in the rate at which they leach out of a given soil; potassium (Kopitke, 1941; Wilde and Kopitke, 1940)(___, ___) and nitrate nitrogen are particularly subject to leaching. Any one element may vary in rate of leaching, depending on the carrier in which it is applied (Wilde and Rosendahl, 1945)(___). Even with the same carrier, rate of leaching may increase with increases in rainfall, artificial watering, and coarseness of soil texture. There may be serious losses of nitrogen compounds, potassium, and replaceable bases when sulfuric acid is applied to soil to control damping-off (Wilde, "Acid," 1937)(___). Whenever leaching appears likely, fertilizer applications should be timed to minimize it or increased to allow for it.

Allowance may also have to be made for the unavailability of nutrient elements because of chemical reaction in the soil (Kopitke, 1941; Mitchell by Shirley, 1939; Wilde and Kopitke, 1940)(___, ___, ___). Phosphorus, for example, becomes increasingly less available as soil acidity increases (Auten, Jour. Res., 1945; Richardson, 1945) (___, ___), especially below a pH concentration of about 5.8 (Chadwick, "Reaction," 1946)(___), and the availability of nutrients in general is low in soils more acid than pH 4.5 (Wilde, 1934)(___). Potassium and the nitrate of sodium nitrate are readily available in highly acid soils (pH 4.5 to 4.0), but potassium becomes rapidly less available as soil reaction approaches neutrality and ammonia nitrogen is most highly available at pH 6.5 to 6.0 (Chadwick, "Reaction," 1946) (___).

Unlike green-manure crops and most organic fertilizers and soil amendments, some inorganic fertilizers tend quite definitely to increase or decrease the acidity of the soil. Inorganic fertilizers therefore must be chosen to avoid undesirable effects on soil acidity, and may be used to make the level of acidity more favorable to mineral nutrition, damping-off control, or the seedlings themselves. The direction of change caused by a fertilizer depends upon the specific, individual carrier, not upon the nutrient element carried. Even slight changes arising from single treatments tend to be cumulative with successive treatments. Chadwick lists sulfur, aluminum sulfate, ferrous sulfate, ammonium sulfate, and ammonium nitrate as carriers increasing soil acidity. Hydrated lime, ground limestone, basic slag, dolomitic limestone, calcium cyanamide, calcium nitrate,

and sodium nitrate, on the contrary, decrease acidity. Potassium nitrate decreases soil acidity slightly. Superphosphate, calcium sulfate (gypsum), magnesium sulfate, muriate of potash (potassium chloride), and potassium sulfate cause little change in soil acidity (Chadwick, "Reaction," 1946)(___). The tendencies of many other fertilizers, especially inorganics, to increase or decrease acidity, are well known, and can be obtained from soils texts (Collings, 1947; Wilde, 1946)(___, ___), State agricultural experiment stations, or fertilizer manufacturers or dealers.

Through its effect on size of seedlings, the amount of one nutrient element present in the soil or added as fertilizer may increase the need for another nutrient element (Davis, Wright, and Hartley, 1942)(___). For example, what may be sufficient phosphorus for seedlings growing to moderate size in the presence of a moderate supply of nitrogen may be wholly inadequate for seedlings growing to larger size as a result of adding more nitrogen. The microorganisms that decompose organic matter in the soil also utilize mineral nutrients, especially nitrogen, that the soil contains, and may do so at the expense of the seedlings if the organisms are very abundant and extra nutrients are not supplied in fertilizers.

Once the desired additions of nutrient elements have been learned from test plots or estimated from soils analyses, comparison with field crop requirements, or the results of past treatments, and have been adjusted to allow for leaching, soil acidity, and the like, the amounts of inorganic fertilizer substances needed to supply them may be calculated. A "complete" commercial fertilizer with a "6-10-7" analysis, for example, contains 6 parts by weight of available nitrogen (as elemental nitrogen, N), 10 parts of phosphorus (as citrate-soluble phosphoric acid, P_2O_5), and 7 parts of water-soluble potassium (as potash, K_2O), plus enough combined elements and inert ingredients to bring the total up to 100 parts by weight (Collings, 1947)(___). Tables are available (Whittaker, 1949)(___) showing the percentages of nitrogen, phosphoric acid, and potash in the commonly obtainable inorganic fertilizer materials, and the amounts of the various materials required to provide specific quantities of nitrogen, phosphorus, and potassium. These tables are a great convenience both in calculating rates of application and in finding the cheapest carriers of the nutrient elements at current prices.

Where difficulties are experienced with injuries to young seedlings from excessive concentrations of nitrogen or potassium, or with serious leaching of these nutrients before the seedlings can use them, part or all of the fertilizer can be applied at intervals during the growing season instead of before sowing. Although excessive late-season fertilization, especially with nitrogen, seems likely to force growth just before lifting and to reduce plantation survival, light periodic applications, including late-season applications of potassium, hold much promise and deserve thorough

testing. (Phosphorus applied as superphosphate is much less likely to injure seedlings or to leach out than are nitrogen and potassium, and is much less effectively applied as a top dressing; the total amount of phosphorus required should therefore be applied before sowing, though perhaps better in granulated than in powdered form.) Relatively insoluble carriers of nitrogen and potassium may be another means of reducing injuries or leaching.

Drill-sown seedlings can be side-dressed mechanically with dry fertilizers until too large to let the fertilizer tubes pass between the drills. <u>Provided the fertilizer solution is washed off the foliage and into the soil immediately afterwards by means of overhead sprinklers, to prevent burning of the foliage</u>, both drill-sown and broadcast-sown seedlings at any stage of development can be fertilized at suitable rates with any of the common, water-soluble carriers of nitrogen or potassium, or with phosphorus carriers in suspension, by dissolving or suspending the fertilizers in water and applying them to the beds with a low-pressure spray rig. Fertilizers applied in either of these two ways (Allen, R. C., 1942; Andrews, 1941; Auten, Jour. Agr. Res., 1945; Brener, 1939; Hartley, 1935; Kopitke, 1941; Wilde, 1946; Wilde and Rosendahl, 1945; Wilde, Wittenkamp, Stone, and Galloway, 1940)(___, ___, ___, ___, ___, ___, ___, ___, ___) when the stock is fairly well grown may meet its nutrient requirements at their peak, with minimum harm to the seedlings and with much smaller losses by leaching than occur when fertilizer is applied before sowing.

<u>Green Manure, Cover, and Catch Crops</u>

<u>Green manure</u> or soiling crops are grown to add nutrients and organic matter to the soil. They are not harvested, but are plowed or disked into the soil on which they have grown. They necessitate increasing the seedbed area of southern pine nurseries by at least 50 and usually by 100 percent, so that part can be in green manure crops while the rest is producing pines.

<u>Cover</u> crops are grown to protect the soil from erosion and sometimes from the sun, and to choke out weeds.

<u>Catch</u> crops are grown to utilize, hold, and return to the soil the nutrients added currently or already in it, lest they leach out or otherwise become unavailable to seedlings grown later on.

Although most green manure crops are grown during the summer, and many cover and catch crops over winter, one crop may serve simultaneously as catch crop, cover crop, and green manure.

In the early and middle thirties many nurserymen began growing green manure crops, usually legumes, in attempts to build up obviously depleted or deteriorating southern pine seedbeds. Similar

practices had already become fairly common in forest nurseries in the Northeast (Soc. Am. For., 1932)(___).

In the South it was soon discovered that satisfactorily heavy green manure crops could be produced only if the plants were fertilized, and that commercial fertilizers usually could be introduced into the soil through the green manure crop with fewer undesirable effects on southern pine seedlings grown the following year than if they were applied immediately before sowing the pines. Both these findings are consistent with results obtained with other species of seedlings and in other regions (Brener and Wilde, 1941; Chadwick, Fertilizer, 1946; Miller, 1947; Slavin, 1947)(___, ___, ___, ___).

Legumes have generally been preferred for green manure, cover, and catch crops in southern pine nurseries, because they add much-needed nitrogen to the soil; their effect on the carbon-nitrogen ratio (Thompson and Smith, 1947)(___), however, requires further study. Clay, Whippoorwill, and other short-lived varieties of peas have generally been grown as two crops, sown in April or very early May and in late July or in August, and turned under in July and October, respectively, or sown in May after spring vetch, and turned under in September. Many nurserymen have found a single crop of velvet beans or soy beans, sown in April or May and turned under in late August or in September, preferable to double crops of peas for summer green manure crops. *Crotalaria spectabilis* and *Sesbania macrocarpa* have, in general, been less satisfactory than peas or beans for summer green manure crops, though *Sesbania* has the advantage of germinating better than most green manure plants on dry sites.

For winter or spring cover and catch crops several different vetches, Austrian winter peas, Italian rye, oats, and mixtures of oats and vetch have proved well adapted under one or another set of circumstances, and winter vetch and varieties of lespedeza have been used as cover crops in paths in winter and spring.

Choice of green manure, cover, and catch crops in any locality should be guided by local practices; the advice of the county agricultural agent, the Soil Conservation Service, and the State agricultural experiment station; the considerable literature on the subject (Alexander, 1939; Brown, Johns, and Haddon, 1944; Ligon, 1945; McKee, 1947; McKee and McNair, 1948; Wasson and Percy, 1942; and later State and Federal publications)(___, ___, ___, ___, ___, ___, and later State and Federal publications); and small-scale tests in advance of general use. The following general precautions are necessary in choosing and growing such crops:

Some green-manure crop plants, or certain varieties of them, are susceptible to nematodes, while others are fairly resistant (p. 247). When there is any suspicion of a nematode problem, green manure crops should be selected in the light of the most recent

information obtainable from the State agricultural experiment station and the U. S. Bureau of Plant Industry, Soils, and Agricultural Engineering, Washington, D. C., concerning nematodes and host plants.

Legume green manure crops may develop poorly, or fail, unless inoculated with nodule-forming bacteria. The State agricultural experiment station or the local county agricultural agent is usually the best source of information on inoculation.

To function effectively as cover crops for keeping down weeds, plants sown in rows at wide spacing (such as cowpeas, velvet beans, and soybeans) usually have to be cultivated until the plants in adjacent rows have grown almost together. Otherwise weeds will come up and go to seed between the rows, to the detriment of pine seedlings the following year.

Winter cover or catch crops, or green manure crops sown early in the spring, may attract egg-laying adults of cutworms, and give rise to outbreaks of these destructive insects. Seedbeds near such crops, and the crops themselves, should be inspected daily, and poison bait should be spread upon the slightest indication of a rapid increase in cutworm population (pp. 241 to 242).

Sowing pine too soon after turning in a green manure or similar crop may result in severe damping-off (especially if the green manure is a legume), nitrogen-starvation (especially if the green manure is a non-legume (Pinck, Allison, Gaddy, 410, 1946; Pinck, Allison, and Gaddy, 421, 1946)(___, ___)), or other injury. Davis and co-workers recommend turning under such crops at least one month before sowing pine (Davis, Wright, and Hartley, 1942)(___). This period may perhaps be shortened by a few days in the case of very light winter cover or catch crops, such as Austrian winter peas, or even oats, turned under when spring temperatures have become high enough for quick decomposition. Extreme caution is advisable, however, and as a rule the period should be lengthened rather than shortened.

Turning under a green manure crop, such as velvet beans, in the fall, especially if no winter cover or catch crop is grown, may result in avoidable erosion and also in leaching of much of the nutrient material in the green manure crop. There is some evidence that it is better to leave the cover crop on the surface of the ground all winter and to turn it under in the spring (McKee, 1947; Tidmore and Volk, 1945)(___, ___) just long enough before sowing to avoid risk of injuring the pine seedlings. Such deferred turning-under has worked well in a few nurseries and deserves thorough trial under various local conditions.

Composts, Organic Supplements, and Other Soil Amendments

Abundant soil organic matter is credited with lightening and loosening heavy soils, decreasing crusting and erosion, increasing moisture-absorptive and moisture-retentive capacity (especially of light soils), increasing cation-exchange capacity, reducing loss of nutrients by leaching, preventing injury to young plants by high concentrations of nutrients, and reduction of Sclerotium bataticola (p. 255)(Auten, Jour. Agr. Res., 1945; Bear, 1946; Brener and Wilde, 1941; Slavin, 1947; Thompson and Smith, 1947; Wilde, 1946; Wilde and Wittenkamp, 1939)(___, ___, ___, ___, ___, ___, ___). So enthusiastically is soil organic matter regarded by many that there is danger of its being expected to cure ills with which it has no connection--poorly stored seed for example. Undeniably, however, heavy applications of organic matter have conspicuously improved many southern nursery soils.

In some instances green manure crops have produced the improvement attributed to increased organic matter. In one nursery, a sheet-eroded knoll incapable of producing pine seedlings was made highly productive by growing and plowing under two crops of cowpeas a year for two years. Such cases are exceptional, however. In general, turning under the best of green manure crops in alternate years, without applying additional organic remains from other sources, seems likely to do little more than maintain soil organic matter at the existing level (Brener and Wilde, 1941; Holley, Stacy, Bledsoe, Boggess, and Brown, 1948; Miller, 1947; Muntz, 1944; Slavin, 1947; Thompson and Smith, 1947; Wilde, 1946)(___, ___, ___, ___, ___, ___, ___). Auten questions whether green manure crops can do even this (Auten, Jour. Agr. Res., 1945)(___).

Increases in organic matter great enough to put the nursery soil in optimum condition may therefore depend in many cases upon the addition of vegetable remains produced elsewhere than on the seedbed area. This is true particularly of localized "galled spots." In southern pine nurseries some form of compost has been widely and successfully used for such additions.

Compost consists of organic remains allowed to decompose in piles or pits, alone or in mixture with soil, inorganic fertilizers, or both. Many different substances have been used fairly successfully for compost--stable or barnyard manure, stable litter, weeds, grain straw, woods leaf litter, tobacco waste, pulpmill waste (Masonite process), bagasse, and sawdust. Moss peat, recommended by many authors, ordinarily is not available in the South at reasonable cost. Pine cones, though available from seed extracting plants at many nurseries, are not recommended, as they seem to decompose too slowly even when shredded.

Muntz increased the producing capacity of a heavy nursery soil by 25 to 50 percent or more (measured in terms of numbers of seedlings per square foot and percentages attaining "plantable" grade), by applying 1 inch of rice straw compost, or 23 tons per acre, dry weight (Muntz, 1944)(___).

This heavy and expensive application of compost has been found, in practice, to be excessive. Region 8 of the U. S. Forest Service has made much lighter applications of the same compost (estimated at 1/8, 1/4, and 1/2 inch, or 3,6, and 12 tons dry weight per acre), sometimes directly before sowing pine, sometimes only before sowing the green manure crop grown in alternate years. Both methods of application have been distinctly beneficial. Several State nurseries have found similar treatments satisfactory. Applications in excess of 1 inch reduced germination, increased mortality of very young seedlings, and distorted the roots of older seedlings by leaving too much irregularly distributed compost near the surface (Muntz, 1944)(___). In the larger-scale, lighter applications such troubles have been rare, though there have been some chlorotic patches when the compost has been applied immediately before sowing the pine. Legumes, such as velvet beans, seem to suffer less injury than pine seedlings from imperfectly decomposed compost or from irregular distribution of the compost in the soil.

The process of preparing the rice-straw compost used by Muntz and Region 8, with other pertinent data and comments, is given on p.560. The chief obstacle to using compost in southern pine nurseries has been the difficulty of getting raw material at sufficiently low cost, but some compost can be made at almost any nursery for use on small areas of the least productive soil, such as sheet-eroded spots, or patches of coarse sand or heavy clay.

Frequently it is suggested that either organic amendments other than composts, or inorganic amendments, be used to lighten heavy soils or to increase the fertilizer- and moisture-holding capacities of coarse sands. Substances recommended or tried have been clay (on sands), topsoil (on clay), sand (on clay), and (on a great variety of soils) charcoal, moss peat, bagasse, chopped grain straw, chopped pine needles, hardwood leaf litter, stable or barnyard manure, tobacco waste, pulp-mill waste (Masonite process), and sawdust (Andrews, 1941; Auten, Jour. Agr. Res., 1945; Howell, 1932; Lenhart, 1934; Tryon, 1948)(___, ___, ___, ___, ___). Results have been highly variable and some of the suggested treatments would be impracticable on any large scale.

Good topsoil has improved both sands and clays in some instances, and sandy topsoils have improved clays, but their use is seldom feasible over large areas. Very finely divided charcoal may be physically beneficial to excessively heavy and to very light soils in some circumstances, but this has not been demonstrated in southern nurseries. Applications of undecomposed organic matter without accompanying inorganic fertilizers have frequently done more harm than good. In one direct comparison, chopped rice straw, chopped pine needles, granulated moss peat, bagasse, hardwood sawdust, fine hardwood charcoal, and fine quartz sand, applied without fertilizer and worked into the soil before sowing, all affected the four principal southern pines adversely as compared to untreated checks or to additions of compost or of virgin

topsoil (unpublished data). With the exception of sawdust, the materials mentioned offer little promise in southern pine nurseries.

Sawdust, however, applied with suitable amounts of fertilizers, appears to be an excellent means of building up desirable quantities of organic matter in southern pine nursery soils without injuring the seedlings. It appears to leave no toxic residues, although it may sometimes alter soil acidity. It is easy to measure, apply, and work into the soil. It is almost universally available at little cost. So far as is now known, either pine or hardwood and either fresh or weathered sawdust may be used. It has given good results with a variety of crops, and has worked well with southern pine seedlings both when applied shortly before sowing the pines and when applied before sowing the preceding green manure crop. (Anonymous, sawdust, 1945; Geesaman and Norris, 1943; McCool, 1948; McIntyre, "Wood," 1948; Northeastern Wood Utilization Council, 1945; Turk, 1943; Viljoen and Fred, 1924)(___, ___, ___, ___, ___, ___, ___)(unpublished data.)

Sawdust contains very little of the three principal mineral nutrients--perhaps only 4 pounds of nitrogen, 2 pounds of phosphorus (as P_2O_5), and 4 pounds of potassium (as K_2O) per ton, air-dry (Turk, 1943)(___). Most of the total weight of sawdust consists of lignin, which decomposes slowly under almost any condition and is therefore capable of adding long-lasting, finely divided organic matter to the soil, and of cellulose, which decomposes very quickly when attacked by microorganisms under certain conditions and furnishes abundant energy for their growth.

In a pile, sawdust decomposes slowly, because decay fungi, although they have an abundant source of energy, lack mineral nutrients. When sawdust is spread on or mixed with the soil, it decomposes much more rapidly because the decay organisms can get from the soil the mineral nutrients they need. They get them, however, at the expense of the pine seedlings or other plants growing in the soil. These become stunted or die for lack of the nutrients tied up in the bodies of the microorganisms. The nitrogen needed by the seedlings is especially likely to be reduced below safe levels in this way. When the sawdust has been completely decomposed, most of the microorganisms die for lack of food, and the mineral nutrients they contain again become available to the seedlings. The soil is likely to be greatly improved physically by the decomposition process and the finely divided organic matter from the dead microorganisms, and by the gradual breaking down of the lignin in the sawdust. The whole process is like that described by Pinck and co-workers and by others for straw. (Mooers, Washko, and Young, 1948; Pinck, Allison, and Gaddy, 410, 1946; Pinck, Allison, and Gaddy, 421, 1946)(___, ___, ___)

Nitrogen may be applied with the sawdust in almost any form--inorganic nitrogen fertilizers, dried blood, or stable manure. The exact quantities of nitrogen and of other mineral nutrients that must

be added undoubtedly vary with local circumstances, especially current soil fertility level. Turk recommends adding elemental nitrogen equivalent to 2 percent of the air-dry weight of the sawdust, or about 225 pounds of sodium nitrate or 180 pounds of ammonium sulfate per ton (Turk, 1943)(___). Pinck and co-workers recommend adding 1.2 to 1.6 percent of nitrogen to wheat straw (Pinck, Allison, and Gaddy, 410, 1946)(___), the chemical composition of which somewhat resembles that of sawdust.

General recommendations cannot yet be made for rates of fertilization in connection with sawdust applications in nurseries, but the following treatments with pine sawdust have given excellent results (including high plantation survival) in one southern pine nursery and promising results in several others:

When used before sowing pine, sawdust is applied at the rate of 15 tons (air-dry weight) per acre (this is approximately 3/4 inch deep) after applying 2,000 pounds of 20-percent superphosphate (400 pounds of P_2O_5) and 400 pounds of 50-percent muriate of potash (200 pounds of K_2O) per acre. The sawdust and fertilizers are plowed or disked into the soil together, to a depth of about 6 inches but not more than 8 inches. Beds are made up and pine seed sown in the usual manner. Beginning about June 1, or a little before if sowing has been early or seedlings begin to yellow for lack of nitrogen, 4 applications of ammonium nitrate, each of 120 pounds (40 pounds of nitrogen) per acre, are made at about 1-month intervals. These top dressings may be applied dry or in solution, but if they are applied in liquid form the beds must be sprinkled <u>immediately</u> and <u>thoroughly</u> to wash the fertilizer solution off the foliage and prevent burning. If continuous production of pine without intervening green manure crops is desired, the same quantities of phosphorus, potassium, and nitrogen, but with only 10 tons of sawdust per acre (about $\frac{1}{2}$ inch deep) are suggested for the second and later years.

When production of pine is postponed until the second year after sawdust is put on, and a green manure crop is grown the first year, sawdust, 20-percent superphosphate, and 50-percent muriate of potash are applied as in the preceding paragraph, together with 600 pounds of ammonium nitrate (200 pounds of nitrogen) per acre. All are plowed or disked in together to a depth of about 6 but not more than 8 inches, and the green manure crop is sown in the usual manner. At the correct stage of development the green manure crop is turned under, to be followed by fall-sown longleaf or by a winter cover crop preceding spring-sown pine of any species. For subsequent alternate-year green manure crops, equal amounts of inorganic fertilizers but only 10 tons of sawdust per acre are suggested. The heavy fertilization of the green manure crops should make direct fertilization of the pine seedling crops unnecessary, but if the pine seedlings yellow for lack of nitrogen, one or more nitrogen top-dressings are added as needed, at a rate not exceeding that in the preceding paragraph.

In the foregoing treatments, carriers other than those listed may be used to add equal amounts of phosphorus, potassium, and especially nitrogen (Whittaker, 1949)(___). For the same amount of sawdust, however, different soils may require more or less of any of the three nutrient elements than is specified here. The best way of learning the correct combination for any soil is by means of small test plots (p. 63) treated with 1/2 to 3/4 inch of sawdust and with fertilizers at the rates specified here and at somewhat lower and higher rates.

Mycorrhizae and Soil Management

Under a wide variety of conditions, mycorrhizae are helpful or essential to good mineral nutrition of southern pines. In particular, instances have occurred in which southern pines have languished or died until accidental or deliberate inoculation of the soil with suitable fungi has led to the formation of mycorrhizae, whereupon nutrition and subsequent growth of the pines has greatly improved. (Auten, Jour. Agr. Res., 1945; Davis, Wright, and Hartley, 1942; Hatch, 1936; Hatch by Doak and Hartley, 1937; Latham, Doak, and Wright, 1939; McComb, 1938; McComb and Griffith, 1946; Miller, F. J., 1938; Rayner, 1948; Young by Hatch, 1936; Young, 1940; Young by Hatch, 1940)(___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___)

Mycorrhizae occur spontaneously all over most southern pine nurseries, and usually most luxuriantly on the best stock. Under such conditions, artificial inoculation of the soil with fungi is uncalled for. If, however, southern pine seedlings develop poorly in nurseries on land long in field crops, or never in pine, or beyond the borders of the southern pine region, the roots should be examined for mycorrhizae. If mycorrhizae are lacking, inoculation should be tried, using soil from beds where mycorrhizae have already begun to develop, or from thrifty pine stands nearby, or possibly using pure cultures of mycorrhizal fungi if suitable soil cannot be obtained in the vicinity.

Immediate Recommendations

1. Erosion should be controlled. Mechanical packing, working of heavy soils when very wet, mixing of heavy subsoil into surface soil, excessive watering, and other procedures which may injure the soil physically should be avoided or reduced, in every possible way.

2. Soil organic matter should be built up to and maintained at a 1.5 to 2.0 percent level by the use of green manure crops, composts, or organic soil amendments. Soils very low in organic matter may require annual or alternate-year applications of 10, 20, or even 40 tons of compost or organic supplements per acre.

3. Fertilizers and other substances added to the soil preferably should be chosen to produce and maintain a pH concentration of slightly above 5.0, but not above 6.0.

4. Unless they result in succulent or oversize stock incapable of good plantation survival, additions of nutrient elements to the nursery soil should at least equal and possibly greatly exceed the average annual quantities required locally for agricultural crops. Phosphorus and nitrogen are especially likely to be required.

5. Any nutrient element added in inorganic form before sowing pines should be applied cautiously, in small to moderate quantities; periodic additions during the growing season, or moderate to heavy applications to the green manure crops instead of to seedlings, may be desirable supplements or alternatives.

6. Applications of lime should be avoided unless there is definite evidence of need for them, and then, for choice, they should be made before green manure crops rather than before pines. Large applications of easily soluble inorganic nitrogen carriers, such as sodium nitrate, or of easily decomposed organic nitrogen carriers, such as cottonseed meal or dried blood, should not be made when or just before sowing pines, and probably should not be made shortly before lifting.

7. In preference to being left bare for periods of some months, nursery soil should be sown to cover and catch crops that will reduce erosion, keep down weeds, and prevent deterioration of soil structure and leaching of nutrients. Even a cover of weeds may reduce erosion and leaching and return a net benefit if disked in before producing seed or rhizomes.

8. Green manure, cover, and catch crops may have to be selected for their resistance to nematodes. During the winter and spring and until about July, such crops must be watched closely as a source of cutworm outbreaks.

9. Green manure, cover, and catch crops must be plowed in long enough before pines are sown to permit decomposition. One month is about the minimum safe period. Much longer is necessary with very heavy crops.

10. Large applications of organic matter, such as straw, sawdust, or even nonleguminous green manure crops, should not be turned in before a pine seedling crop without adding enough nutrients, especially nitrogen, to supply the microorganisms decomposing the cellulose.

11. Fertilizers should not be incorporated in compost to the extent of more than about 4 percent by weight of nutrient salts, based on the air-dry weight of the compost material.

12. Materials and practices deserving of local trial are: previously little-used raw materials (especially sawdust) for composts and organic supplements; slowly soluble carriers of nutrient elements, especially for green manure crops or for application before sowing pines; application of inorganic nutrient carriers periodically during the growing season, but with care to wash them off the foliage promptly if applied in liquid form; moderate late-season applications of potassium (which seem to improve survival); building up soil organic matter by applying sawdust and nitrogen to legume green manure crops; and leaving late-summer green manure crops on the ground as a mulch over winter instead of turning them under in the fall.

13. In the rare event of there being no mycorrhizae on the seedling roots, inoculation of the beds with mycorrhizal soil or cultures should be tried as a means of improving seedling development.

14. The final proof of the effectiveness of any nursery soil treatment, over and above its cost and its visible effect on the soil, is the plantation behavior of the seedlings it produces. The size and appearance of seedlings are not reliable evidence of their quality. Any drastic change in fertilizer treatment requires planting of the treated seedlings to verify their capacity for high initial survival.

NURSERY COSTS AND RECORDS

Table 22 breaks down into component parts, and expresses both in dollars and in percentages of the whole, the 5-year-average nursery costs, exclusive of costs of seed, given in table 5. These data are based on 196 million seedlings of 4 species, produced in three U. S. Forest Service nurseries during 1937-1941, inclusive, largely with CCC labor at 25¢ an hour and WPA labor at variable but still low rates. All three nurseries were operated at approximately full capacities (20 to 25 million trees a year for the Ashe and Stuart; 3 to 5 million a year for the Ozark), under fairly well stabilized practices and with a fairly high degree of mechanization. Each nursery was in charge of an experienced technical nurseryman whose time was charged to administration when not directly chargeable to specific operations. The data are the most complete and detailed available on the cost of large-scale production of southern pine nursery stock.

The four total nursery costs (each an average for four or five years) in table 22 vary from $2.13 to $4.99 per thousand trees shipped. The costs by species in individual years in the three nurseries varied even more widely: seedling production from $0.22 to $3.81 per thousand; lifting and packing from $0.47 to $1.54; soil fertility maintenance from $0.07 to $0.57, building and equipment maintenance from $0.13 to $1.32; depreciation from $0.17 to $1.41; administration from $0.05 to $1.81; and total nursery costs (exclusive of seed) from $1.65 to $10.11 per thousand. Costs in other southern pine nurseries during the same period probably varied even more widely. Obviously, therefore, no figure in table 22 can be used as a universal average cost applicable to all nurseries in all years, particularly at wages prevailing since World War II. Some estimate of probable nursery costs is, however, necessary to orderly planning, and it is felt that, because of the size and efficiency of the operations and the completeness of the records on which it is based, table 22 is as good a starting point as can be offered for such estimates.

The percentages of total nursery costs charged to individual items of nursery operation in table 22 should be particularly useful guides to nursery management. Like costs in dollars, these percentages varied from nursery to nursery. For instance, the percentage cost of administration was much higher at the Ozark Nursery than at the Stuart because at the Ozark the salary of one technical nurseryman was prorated over only one-fifth as many trees. Under present practices, percentage costs of seedling production might be expected to decrease somewhat because of economies resulting from chemical weeding, and percentage costs of soil fertility maintenance to go up because of more attention to this important item. Such variations are logically to be expected. Except for these predictable variations,

Table 22.--Average nursery costs per thousand plantable trees, Region 8, U. S. Forest Service, nursery years 1937-1941, inclusive 1/

Species, nursery, and item of cost	5-year 2/ weighted average cost per thousand trees: Dollars	Percent of total
Longleaf and slash 3/		
Ashe Nursery		
All, exclusive of seed	2.18	100.0
Seedling production 4/	.53	24.3
Lifting and packing	.66	30.3
Soil fertility maintenance	.14	6.4
Building and equipment maintenance	.21	9.6
Building and equipment depreciation	.35	16.1
Administration	.29	13.3
Stuart Nursery		
All, exclusive of seed	2.48	100.0
Seedling production 4/	.83	33.5
Lifting and packing	.53	21.4
Soil fertility maintenance	.27	10.9
Building and equipment maintenance	.44	17.7
Building and equipment depreciation	.30	12.1
Administration	.11	4.4
Loblolly		
Ashe Nursery		
All, exclusive of seed	2.13	100.0
Seedling production 4/	.50	23.5
Lifting and packing	.67	31.4
Soil fertility maintenance	.14	6.6
Building and equipment maintenance	.21	9.9
Building and equipment depreciation	.32	15.0
Administration	.29	13.6
Shortleaf		
Ozark Nursery		
All, exclusive of seed	4.99	100.0
Seedling production 4/	1.42	28.5
Lifting and packing	1.09	21.9
Soil fertility maintenance	.23	4.6
Building and equipment maintenance	.83	16.6
Building and equipment depreciation	.73	14.6
Administration	.69	13.8

1/ Based on the 196 million trees of table 5; costs of seed are excluded.

2/ Four-year costs only in the case of loblolly pine.

3/ Separate nursery costs were not kept for longleaf and slash.

4/ Seedling production consisted of bed making, sowing, bird patrol, watering, cover removal, cultivation, hand and mechanical weeding, and spraying. Weeding was usually the largest single item (in some years larger than all others combined), and spraying one of the lowest.

however, any great increase in the percentage cost of a particular item, over the percentages given for that item in table 22, should serve as a danger signal.

For example, a disproportionately high percentage cost of seedling production should prompt the nurseryman to: (a) scrutinize his operation for poor organization of work, waste motion, and failure to mechanize (Umland, 1946)(___); (b) check the effects, upon cost per thousand trees shipped, of low tree percent; (c) make sure tardy or inefficient weeding has not run up his weeding costs (Umland, 1946)(___); and (d) check the effect of culling on costs (fig. 27).

In the same way, a great rise in the percentage cost of lifting and packing should lead to a check on: (a) organization and labor efficiency, including the possibility of reducing costs by installing mechanical grading tables; (b) packing methods and cost of packing materials; and (c) the possible effect of sparse stands or excessive culling on lifting-cost per thousand trees shipped.

By attention to such details, good nursery cost records, itemized for each species and geographic seed source as indicated in table 22, can be made a powerful tool for reducing both nursery costs and total planting costs.

One thing should be emphasized, however. Economies should never be carried so far as to reduce the technical excellence of the nursery operation. It is unwise, for example, to gamble on storing longleaf seed at air temperature until late spring sowing, merely to save a small charge for cold storage. Nor should a spraying be omitted, a weeding deferred, or any other sound practice trifled with, just to save a few cents per thousand trees. Above all, in permanent nurseries it never pays to make immediate savings in cash outlay at the expense of soil fertility. Often such economies boomerang by actually increasing the cost per thousand trees shipped, or by reducing the survival or growth of the planted trees.

Records

Nursery records should be complete enough to supply the following data concerning any shipment of stock for which they may be required: species and geographic source of seed (required for all lots shipped); class, age, size (both average and range), and grade of seedlings, and specific rules by which graded; occurrence of insects or diseases possibly affecting plantation survival, and degree to which controlled; length of root pruning; and dips or sprays applied at lifting. For each seedling crop as a whole there should be recorded the temperature, humidity, and rainfall under

which it was grown. Each year, records, as guides to future operations, should be kept of date and rate of sowing; duration of covering; the initial catch of seedlings; weedings, including methods, effectiveness, and injuries to the seedlings; watering dates and amounts; nature and dates of injuries from pests, resulting percentages of mortality and culls, and the nature and effectiveness of control treatments; the final stand, expressed both as percent of seedlings originally established and as number per square foot; and the percentage of plantable seedlings in the final stand. For intelligent application of treatments and purchase of supplies, there must be some records of the dates of development of secondary needles and winter buds, life of equipment, quantity of moss used per bale, numbers of seedlings packed per bale, and the like.

Nursery soil maintenance and treatment records and maps should include: method of ground preparation; fertilizers, soil amendments, crop rotations, and green manure crops (species, fertilization, weight per acre produced, and stage and date of turning under); soil fumigants; chemical weed control; weed populations (species, amount, and whether allowed to form tubers or go to seed); outbreaks of soil insects and diseases, with exact locations, dates of appearance, treatment, and control; location, severity, and control of erosion; periodic measures of pH concentration and of soil organic content; and seedling crops removed, with dates, numbers per square foot, and approximate total weights per acre.

PLANTING

The surest means of attaining success in planting is to keep all phases of the process in balance (Hawley and Lutz, by Littlefield, 1943)(___). A moderate amount of special protection and care after plantations have been established is often more important than special refinements of planting methods. In all situations the best planting techniques depend for complete success upon correct choice of species, seed source, and spacing in relation to the planting objective, and upon the delivery of satisfactory nursery stock. Some failures may be unavoidable, and are best offset by budgeting funds for replanting (p. 405). Such replanting is cheaper than a general over-refinement of planting technique in an attempt to prevent all failures.

This chapter supplies general information on planting technique. Men familiar with the individual sites to be planted are in the best position to diagnose local conditions and fit accepted or new methods to them. In doing so, the survival and growth of nearby plantations are invaluable guides.

PLANTING SURVEYS

Most large tracts require planting surveys 1 to 3 years in advance of planting if they are to be reforested with best results at minimum cost.

Modified to suit local conditions, the planting survey system used by the U. S. Forest Service (U. S. Forest Service, Region 8, 1939) (___) should meet the needs of large-scale planters of southern pines. In this system, preliminary reports are drawn up describing the general area considered for planting. These reports allow the area to be narrowed down to those tracts which are to be planted in the next one to three years, and for which an intensive survey may be necessary.

Each preliminary report is compiled under the following headings: (a) general description of the tract, its location and boundaries, and approximate gross acreage; (b) history of tract, with special emphasis on logging, burning, grazing damage, agricultural use, erosion, and other influences which have made planting necessary; (c) kind, quality, and estimated degree of natural forest reproduction, with stocking expressed as percentage of all 1/1000-acre quadrats occupied, not in terms of total seedlings per acre; (d) approximate stand of brush and weed trees (expressed as in c above), with notes on size and on probable impediment they offer to natural reproduction and to planting; (e) condition of site--especially soil type and drainage--and apparent capacity to grow timber; (f) rodents, insects, and diseases characteristic of the area; (g) extent and nature of use by livestock, and modifications necessary to protect planted trees; (h) fire history and hazard, and steps necessary to control fires effectively; (i) probable cost of intensive planting survey; (j) recommendations for or against making an intensive survey; and (k) sources of the information presented.

The preliminary report is based as far as possible on existing information and personal knowledge. Only such field inspections are made as are essential to confirm doubtful points (such as extent of natural reproduction, or presence of insects or diseases), or to cover areas not described in existing records. Aerial photographs are useful sources of information, but must be checked by field examination wherever pine seedlings, especially longleaf, may exist but are not visible from the air.

For old fields, uniformly denuded tracts of former longleaf pine land, and the like, clearly in need of planting and presenting no complications, the preliminary report is made complete and final by including the net acreage to be planted and the numbers of trees required.

The principal object of the intensive survey of more complex tracts is to learn the net acreage to be planted; to calculate as closely as possible the amount of nursery stock needed for each tract; to locate all roads, firebreaks, sources of water, impassable ground, and other features that may affect planting (including the feasibility of machine planting); to estimate the fencing, firebreak construction, and road construction necessary, with costs and locations; and to determine the need for ant-eradication, gopher control, prescribed burning, and the like, with costs and locations.

Four principal kinds of evidence are considered in classifying land: (1) immediately or potentially merchantable stand of timber species; (2) established natural seedlings of merchantable species; (3) potential natural reproduction from existing trees capable of bearing seed; and (4) presence of brush or weed trees that might hinder planting.

No definition of merchantable stands will be attempted here. There is, however, an increasing tendency to plant openings in sparse or irregular sapling stands, rather than to wait for them to be filled by natural reproduction (pp. 361 to 362).

With regard to natural reproduction already on the ground, Region 8 of the U. S. Forest Service has defined plantability in terms of percentages of all 1/1000-acre quadrats occupied by one or more established seedlings, as follows: Land with less than 11 percent of all quadrats occupied is given the highest priority and that with 11 to 24 percent of the quadrats occupied receives second priority. Land with 25 to 49 percent of the quadrats stocked is regarded as possibly plantable. No attempt is made to plant areas throughout when fifty percent or more of all quadrats are stocked.

Seldom, however, except in old fields, does entirely bare land exist uniformly over one "forty" or square mile. Instead, irregular areas of all four classes of stocking, from an acre or less to several hundred acres in size, are interspersed. In such cases, it is accepted practice to bring the stocking of all of these, including even the best stocked, up to about 1,200 trees per acre (assuming 6-by 6-foot spacing) while the crews are on the ground. Therefore, on all areas selected for planting, the man who orders the nursery stock must know not only the net acreages of each of the four stocking classes, but also the average number of quadrats per acre still remaining to be stocked in each.

In predicting natural reproduction, it is wise to count on little from fewer than 5 to 10 seed trees per acre, to check all areas of possible reproduction by making a rapid reconnaissance the summer or spring before planting, and to have alternative planting areas prepared if reproduction actually has taken place.

Region 8 of the U. S. Forest Service has hitherto classified land as unplantable if 50 percent or more of all 1/1000-acre quadrats have been occupied by brush or weed trees capable of suppressing or killing out the planted pines. Because of urgent need to restore pines to many brushy areas and because of recent advances in the technique of killing undesirable trees (p. 368), this criterion may have to be amended. Nevertheless, it remains a useful index to probable costs of site preparation and planting, and to plantation survival and growth.

The data on merchantable or near merchantable timber, actual and potential reproduction, and brush and weed trees are collected along paced lines run by compass at 20-chain intervals through uniform areas such as denuded longleaf pine land and at 10-chain intervals on more varied sites. The cruise lines are run at right angles to taped base-lines laid out parallel to main topographic features and tied to section corners or other established points. Every 2 chains on cruise lines 20 chains apart, and every 4 chains on lines 10 chains apart, 3 concentric plots are taken, as follows:

1. A 1/5-acre circular plot (radius, 52.7 feet), on which seed trees are counted.

2. A 1/50-acre circular plot (radius 16.7 feet), on which saplings and poles 4.5 feet high to 8 inches d.b.h. are counted.

3. A 13.2-foot square, subdivided into four 1/1000-acre quadrats each 6.6 feet on a side, each of which is recorded separately as being occupied or not occupied by (a) an established seedling or seedlings of desirable species and (b) a bush or weed tree. (Any quadrat is counted as occupied if it contains a sapling, or if more than half of it lies under the crown of a pole or seed tree.)

With either line-plot spacing described, this system gives for every forty acres the seed trees on 2 acres, the saplings on 1/5 acre, and the presence or absence of natural seedlings and of brush on 40 separate 1/1000-acre quadrats. These data are converted into the averages required to summarize the intensive survey.

Pertinent features lying between cruise lines are sketched on field maps (scale usually 4 inches to the mile). On the same maps are shown areas infested with ants or gophers, as a guide to crews controlling these pests, and any other information important to have during planting. Data on seed trees, stocked and unstocked quadrats, etc., are recorded on suitable tally sheets, by line and plot numbers corresponding to those shown on the field maps. The data from the field map sheets and tally sheets are summarized on planting-plan maps

(scale usually 2 inches to the mile), in tables of net acreages to be planted and of quantities of nursery stock required, and in a detailed written statement following essentially the outline used for the preliminary report.

THE PROBLEM OF INITIAL SURVIVAL

The earliest indication of how successful a southern pine plantation may be is its initial [38] survival. Final results may be

38/ Survival the first October to December after planting, unless otherwise specified. The survival in June often is a satisfactory index, but becomes misleading if summer mortality is high.

acceptable even when initial survival is only fair, provided later mortality is low and growth is good. Each decrease in initial survival, however, increases the average cost of the trees that reach merchantable size, and correspondingly decreases profits. By irregularly opening up the stand, low initial survival may increase fusiform-rust infection or otherwise reduce the quality of the products. It may have legal complications, as in payment of benefits for agricultural conservation practices. Lastly, there are minimum levels of initial survival below which nobody can accept plantations as successful.

The planter is more immediately concerned than anyone else with the whole problem of initial survival. His judgment in accepting stock and competence in planting it largely determine whether initial survival will be high. If it is low, he is the first to discover the fact, and is in the best position to learn the reason. If an error in planting technique causes failure, only the planter can correct it. Even when the trouble lies in the quality or condition of the stock delivered from the nursery, the nurseryman can learn of and correct the trouble only if the planter calls it to his attention. For these reasons the planter must understand the effects of both nursery and planting practices upon initial survival.

Planting costs money and effort. Death of any large percentage of the planted seedlings cannot be glossed over; it is conspicuous and disturbingly final. Nobody likes it. Therefore much investigative effort throughout the southern pine region has been concentrated upon influences thought to affect initial survival. The general results of these investigations may be summed up as follows.

Except possibly in the Piedmont, initial survival of planted southern pine has been much more variable, and often much lower, than is generally realized. In many instances it has been 60 percent or less (Coulter, 1946; Georgia Department of Forestry, 1949; Preston, 1943)(___, ___, ___). In controlled experiments over an 11-year period, survivals of stock planted under good to ideal field conditions (pp. 277 to 278) ranged as low as 28 percent.

Although necessary to it, high initial survival does not insure high survival when the crowns close or when the trees reach merchantable size (Preston, 1943)(___). Under the plantation management practices that have so far prevailed in the South, this has been most frequently true of longleaf pine, which, in the absence of prescribed burning to control brown spot, has tended to suffer continuing mortality between the second and tenth or sometimes between the tenth and twentieth years (fig. 7, D and E, page 42a). Planted loblolly (fig. 7, A and B), slash (fig. 7, C), and shortleaf are more likely to maintain a nearly constant level of survival from the end of the first year until after the crowns have closed, as have also pines in other regions (Gibbs, 1948; Hendrickson and Gibbs, 1949; Minckler, 1943; Schopmeyer, 1940; Spiers, 1932; Wood, 1936)(___, ___, ___, ___, ___, ___). In zones of heavy fusiform rust (fig. 4, p. 15a), however, slash may suffer continuing mortality like that of longleaf. Other exceptions are discussed under plantation injuries.

Incorrect planting is not the only and may not be the most frequent cause of poor initial survival. Assuming arbitrarily that all failures are the planter's fault often results in costly annual losses which could easily be prevented by correcting some error in planting policy or nursery practice.

Exaggerated notions of the effects of planting technique on initial survival have sometimes led to over-refinements of the planting process, including those of tool design and manipulation. Within wide limits, design and use of tools have little influence on survival; their principal effects are on efficiency of labor output.

The most widespread, frequently occurring, and generally feared cause of low initial survival in southern pine plantations is not fire, animals, insects, or disease, but drought (Chapman, A. G., 1944; Coulter, 1946; Hursh, 1948; Kozlowski and Scholtes, 1948; Maki and Marshall, 1945; Morriss and Mills, 1948; Schopmeyer, 1939; Smith, B. F., 1932)(___, ___, ___, ___, ___, ___, ___, ___). This has been found true of direct-seeded southern pine also (McQuilkin, J. A. R., 1946)(___), and of planted American pines in general (Daubenmire, 1943; Fowells and Kirk, 1945; LeBarron, Fox, and Blythe, 1938; Marshall and Maki, 1946; Rudolf, 1939; Schopmeyer, 1940; Shirley and Meuli, 1939; Wilde and Patzer, 1940)(___, ___, ___, ___, ___, ___, ___, ___). Drought, in the sense of loss of more water from the tops than can be replaced through the roots, is insidious in that it may affect seedlings not only through dry winds, heat, and lack of rain, but also through unfavorable soil texture, lack of soil organic matter, freezing of the soil, competing vegetation, physiological condition of the planting stock, injury to roots during lifting, foliage sprays applied at lifting time, too high setting of the seedlings in planting, planting slits left open at the top, and doubtless in other ways. It is the more troublesome and baffling because the planter can neither escape dry years or briefer dry spells, nor

(especially in erosion or flood control) confine his efforts to the moister sites. For these reasons, the majority of attempts to explain or improve poor initial survival must take into account the numerous different ways in which drought may have injured the seedlings.

The ability of planted southern pines to overcome drought and attain high initial survival seems to depend, perhaps even more than that of pines planted in other regions, upon formation of considerable new root tissue promptly after planting (p. 287) (Kozlowski and Scholtes, 1948; Maki and Marshall, 1945; Schantz-Hansen, 1945)(___, ___, ___). The climate of the southern pine region and the inherent characteristics of the southern pines themselves encourage such tissue formation; the nurseryman may modify it favorably or unfavorably, directly or indirectly, in many different ways; the planter has little chance of affecting it except by flagrant abuse of the stock.

Influences which affect initial survival through choice of species and in similar ways have been discussed on pp. 5 to 53 or are treated under grades of nursery stock or plantation injuries. The following sections discuss the way site preparation, season and weather, condition and care of stock, and methods of planting affect initial survival. These are influences which the planter can circumvent or control, either through his own knowledge and efforts, or with the help of the nurseryman. Most of the information presented is from studies on cutover longleaf pine land at Bogalusa and Alexandria, Louisiana (pp. 502 to 506). The studies included 430 different treatments affecting initial survival, applied to 1,170 separate lots of stock totalling 143,000 seedlings of the 4 principal southern pines.

SITE PREPARATION

The common ways of preparing sites before planting southern pines are by burning, by furrowing, and by scalping spots.

In rigorous studies on the Johnson Tract (p.504) in several different years, burning immediately or one year before planting, or furrowing the site or scalping spots, produced neither large enough nor consistent enough increases in initial survival to justify general use on cut-over longleaf pine land. In a few instances these measures reduced survival significantly.

Excellent survival on thousands of acres of unprepared sites both within and outside the longleaf pine types, from Georgia and Florida westward to Arkansas and Texas, supports the conclusion that site preparation is generally unnecessary to satisfactory initial survival in the southernmost part of the southern pine region. The same seems true of most southern pine planting sites in the Central, Piedmont, and southern Appalachian regions (Gibbs, Forest Farmer, 1948; Hendrickson and Gibbs, 1949; McLintock, 1940; Minckler and Chapman, 1948)(___, ___, ___, ___), and presumably in the Atlantic Coastal Plain also.

Site preparation may nevertheless reduce costs of planting or of plantation protection enough to be worth while even though it does not increase, or actually somewhat decreases, initial survival. Moreover, on some adverse sites, site preparation may be more important to good initial survival than it is on the commoner sites on which it has been systematically studied. The different methods of site preparation and suggestions for their use which follow, however, should be examined critically in the light of local conditions, and tried experimentally before large-scale adoption.

Burning

Burning is the cheapest form of site preparation. It usually costs only a few cents an acre. The essentials of prescribed burning are outlined on p. 400, and pertinent details concerning the effects of burning are available in the literature (Bickford and Bruce, 1948; Byram, 1948; Byram and Lindenmuth, 1948; Goodell, 1939; Greene, 1935; Heyward, 1938; Heyward and Barnette, by Coile, 1934; Hopkins, 1949; Kramer and Weaver, by Turner, 1936; Minckler, 685, 1941; Morriss and Mills, 1948; Muntz, SFN 57, 1948; Siggers, 1934; Siggers, 1944; Siggers, 1945; Thompson and Smith, 1947; Wahlenberg, 1935; Wakeley, 1935; Wilde and Patzer, 1940)(___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___).

On many sites, burning either immediately or a year before planting makes hand planting easier, and burning immediately before makes machine planting very much easier. Burning immediately before planting gives the planted trees almost complete fire protection through the first growing season and may reduce fire hazard through the following winter. It frequently enables planted slash or loblolly pine seedlings to overtop gallberry or wax myrtle without further aid. Burning off old, heavy grass rough immediately or even one year before planting may prevent serious injury of planted trees by rodents, especially cotton rats.

On sites already partly stocked with natural longleaf seedlings, prescribed burning immediately before planting usually does not kill the natural seedlings, and may even save them from brown spot. It also enables the planter to see which planting spaces are already occupied. If longleaf seedlings are planted, it delays and reduces their infection by brown spot.

These advantages of burning must be weighed against several disadvantages.

Burning kills small slash and loblolly pine seedlings already established on the site, and may kill longleaf after it has first started height growth. It kills back small established shortleaf pine seedlings, though they usually sprout after fire.

The earlier growth of grass on burned than on unburned areas may cause cattle to concentrate on the planting site. The cattle sometimes browse the planted pines severely for lack of other roughage or green feed and may also injure them by trampling.

Sometimes burning immediately before planting causes serious mortality among the planted seedlings from severe freezing or, when dry weather follows planting, from extreme exposure to sun and wind. Burning should therefore be used with caution in localities where freezing or dry spells in the winter or early spring are to be expected.

Furrowing

Plowing furrows, although cheaper than scalping spots by hand, is more expensive than burning; in one large-scale operation, furrowing at 8-foot intervals for planting at 6- by 8-foot spacing made up 8 percent of the total planting cost (Smith, B. F., 1932)(___). Purely as a means of improving initial survival, it is a doubtful investment on the great majority of southern pine planting sites. In most places it has been abandoned as unnecessary even though (in addition to any effects it may have on survival) it makes bar or mattock planting quicker and easier, simplifies control of spacing, and helps

protect the trees from fire for the first year or two after planting (Coulter, 1946; Gibbs, Forest Farmer, 1948; Hendrickson, 1945; McLintock, 1940; Minckler and Chapman, 1948; Wakeley, 1935)(___, ___, ___, ___, ___, ___).

Furrowing is used, and apparently to good advantage, on sites heavily vegetated or deficient in rainfall (Cummings, 1945; McCormick, 1948; Minckler and Chapman, 1948)___, ___, ___). Moist sites occupied by dense stands of gallberry and palmetto are a case in point, as are drier sites occupied by Bermuda grass, carpet grass, or lespedeza (Hendrickson, 1945)(___). It has also improved both initial survival and later growth on flat, very wet sites, either poorly drained "crawfish flats" or the distinctive low pockets known locally as "savannas" (Morriss, 1939)(___). On these poorly drained sites the furrows are located to improve drainage as much as possible, and the trees are planted, not in the furrows, but on the furrow slices, as has been done on similar wet sites in the Lake States (Stoeckeler, "drainage," 1947)(___).

Except on excessively wet ground, furrows on southern pine planting sites usually are made only 2 or 3 inches deep, just deep enough to prevent regrowth of grass from the roots. On sandy soils, deeper furrows result in too much movement of sand into the furrows; where shallow surface soils overlie stiff subsoils, deep furrows may place too much of the seedling root system in the less fertile, less penetrable subsoils. Furrows should be plowed at least 2 or 3 months before planting, to let rain settle the loose soil. They often remain plantable for a year and sometimes for 2 years after plowing. Narrow furrows made with a turning plow are preferred for longleaf because they minimize silting; wider furrows, made with a scooter stock, middle breaker, disk, or special fire-line plow usually are preferred for other species. Furrowing on or near the contour is preferable except on poorly drained sites, and is essential on steep slopes or any easily eroded soil.

Scalping

Scalping consists of removing the surface vegetation from spots 15 to 20 inches across (8 to 10 inches under Central States conditions (Minckler and Chapman, 1948)(___)), cutting just deep enough to prevent regrowth of the grasses from the roots. In mattock-planting, scalping usually is done with the mattock at the time of planting; in bar-planting, it usually is done in advance, with mattocks or heavy hoes. It has been substituted for furrowing in a generally successful attempt to reduce erosion and silting, but usually costs more because of the hand labor involved. With occasional exceptions (Hendrickson, 1945)(___) it has resulted in much the same initial survival as has planting in plowed furrows or in unmodified rough (Erickson, 1939; Gibbs, Forest Farmer, 1948)(___, ___)(unpublished data, U. S. Forest Service). It is not recommended except where local experience or

tests show that it meets a need for reducing competing vegetation and increases initial survival enough to justify the extra cost.

Subsoiling

Breaking up stiff subsoils or existing hardpans with a "bull-tongue" or "ripper," in conjunction with furrowing, has been tried in a few places, but the results do not justify recommending this practice as a means of increasing initial survival (Gibbs, Forest Farmer, 1948; Hendrickson, 1945)(___, ___).

Strip Plowing

The plowing of broad strips or of the entire site is too expensive for general use. Although it has sometimes increased early height growth, it has rarely improved and has sometimes reduced survival (Coulter, 1946; Gibbs, Forest Farmer, 1948; Hendrickson, 1945; McLintock, 1940)(___, ___, ___, ___). Because it may increase height growth, it should be avoided in planting loblolly and slash pines where risk of fusiform-rust infection is high (pp. 395 and 412).

Special Measures on Severely Eroded Land

In extreme cases, seedlings cannot even be set in place on eroded soils until gully banks have been plowed or blasted down, check dams or soil-collecting trenches have been built or dug across gullies, or natural hollows or holes dug with post-hole diggers have been filled with topsoil from other areas (Hendricks, 1938; Hendrickson, 1945; Hendrickson and Gibbs, 1949; Meginnis, Jour. For., 1933; Meginnis, Farmers' Bul., 1933; Meginnis, 1938; Meginnis, 1939) (___, ___, ___, ___, ___, ___, ___). These and other special methods of preparing eroded sites are, however, expensive, and it seems probable that site-preparation has often been overdone. Much erosion-control planting has been astonishingly successful without it, and in many instances over a wide territory (Gibbs, Forest Farmer, 1948) (___) special measures other than mulching have had no apparent effect on survival.

Mulching of the kind discussed here consists of "applying on the ground a thin, uniform coating of....pine branches, leaf litter, grain straw, Lespedeza sericea stems, or cane bagasse. It does not include the practice, often used....in the South, of throwing brush haphazardly into gully bottoms and ditches, or of smothering the ground with straw as is commonly done for winter protection in the North" (Franklin, 1939)(___). Mulch may be applied broadcast over the site well in advance of planting--this may make the soil much looser and moister at planting time--or may be applied broadcast or around individual trees at or after planting. McQuilkin spread

Virginia pine litter or broomsedge (Andropogon sp.) 2 inches deep in 18-inch circles around planted trees; Hendrickson mulched the entire site with pine straw (Hendrickson, 1945; McQuilkin, Jour. For., 1946)(___, ___). The degree of mulching can be adjusted to local needs, and methods developed for roadbank fixation (Anonymous, Road banks, 1935; Hursh, 1938)(___, ___) may be useful on very rough sites.

On bare and particularly on eroded or actively eroding sites, mulching has greatly increased both survival and early growth of southern pines on different soils in many different localities (Cummings, 1945; Hendrickson, 1945; Hendrickson and Gibbs, 1949; Ligon, 1940; McQuilkin, Jour. For., 1946)(___, ___, ___, ___, ___). Natural litter accumulation--"self-mulching"--under pines on moderately eroding sites has conspicuously improved growing conditions in the same way. Gibbs indicates that, in establishing plantations on eroding land, mulching improves survival more than does plowing, cultivating, fertilizing, subsoiling, ridging, furrowing, gully-bank sloping, or the construction of check dams (Gibbs, Forest Farmer, 1948)(___). Mulch greatly reduces rainwash (Kramer and Weaver, by Turner, 1936; Meginnis, Cir., 1935)(___, ___) and frost-heaving (Franklin, 1939; LeBarron, Fox, and Blythe, 1938; McQuilkin, Jour. For., 1946; Wilson, 1939)(___, ___, ___, ___). It adds much-needed organic matter to adverse sites (Stephenson and Schuster, 1946; Thompson and Smith, 1947; Wilde and Patzer, 1940)(___, ___, ___), restores beneficial soil fauna (Jacot, 1936)(___), and may encourage the development of beneficial mycorrhizae (Hatch, by Doak and Hartley, 1937; Neilson-Jones, 1943)(___, ___) where soil-abuse has destroyed them. Mulching has greatly benefited both soil and trees in plantations on wind-eroded soils in the North, and in some instances has been found essential to survival on such sites (Altpeter, 1941)(___).

Brush Elimination

Elimination of brush in advance of planting may be necessary on some sites to give reasonable chances of good initial survival as well as to permit planting at economical speeds. Details are discussed in the section on planting among pines and hardwoods (p. 362).

Allocation of Treatment to Site

The planter can improve average initial survival at minimum cost by confining site preparation and other pre-planting treatments to the trouble spots. The principle is the same as that of assigning two different species or stock grades to different soils even though both are equally adapted to the climatic and other hazards of the area as a whole (Cummings, 1945; Gibbs, Forest Farmer, 1948; McQuilkin, Jour. For., 1946; Maissurow, 1939; Meginnis, Jour. For.,

1933; Schopmeyer, 1939)(___, ___, ___, ___, ___, ___), and as that underlying attempts to develop special drought-resistant stock for adverse sites (Maki and Marshall, 1945; Marshall and Maki, 1946; Ostrom, 1945; Shirley and Meuli, 1938; Shirley and Mauli, 1939) (___, ___, ___, ___, ___).

Furrowing, for example, can be confined to portions of old fields occupied by Bermuda grass, carpet grass, or lespedeza; furrowing and planting on the furrow slice, to savannas; prescribed burning in advance of planting, to gallberry thickets or to areas of grass rough old and heavy enough to harbor cotton rats. Where only portions of an area are heavily infested with rabbits, use of slash or loblolly stock sprayed with rabbit repellents, or late-season planting of these species, can be confined to the infested portions. Where both longleaf and slash are to be planted on an area infested throughout by rabbits, the longleaf can be planted at the beginning and the slash at the end of the season (p. 382). Since frost heaving is worst with small stock, on heavy soils, and on sites unprotected by vegetation, average survival in the northern part of the southern pine region can be increased by using only large stock and planting only on predominantly grassy and sandy sites until the danger from frost is over for the year (Anonymous, Spring or Fall, 1938; Cummings, 1945; Goodell, 1939; McQuilkin, Jour. For., 1946; Minckler and Chapman, 1948; Rudolf, 1937)(___, ___, ___, ___, ___, ___).

SEASON AND WEATHER

Throughout most of the lower South, the optimum planting season extends from about December 1 to March 1. In southern Georgia and Alabama and northern Florida the optimum season ends a month or 6 weeks earlier (fig. 4), but in the northernmost parts of the southern pine region, and especially at high elevations, it may extend through April.

The things that in practice usually determine the beginning and ending dates of planting are: (a) the occurrence of enough fall or early winter rain to soften and thoroughly moisten the soils of the planting sites; (b) spring temperatures and other influences (possibly including vigorous top growth of seedlings) that make trees planted after a certain date unlikely to survive well; and (c) in the northern parts of the southern pine region, a protracted period of freezing weather that separates late fall from spring planting seasons.

Lifting and Shipping Dates

Unless prolonged winter rains make the nursery soil too wet for lifting, shipping ordinarily can be adjusted to the needs and convenience of the planter. Within the acceptable period for planting, the nurseryman must neither lift so far in advance of shipment that the seedlings will deteriorate in nursery storage (p. 272), nor lift in freezing weather. Aside from these two obvious points, most discussion of the effect of lifting and shipping dates upon survival has centered upon the apparent dormancy or non-dormancy of the seedling tops at lifting time.

Top Dormancy

The best evidence suggests that, while near-dormancy of tops may be desirable, non-dormancy alone seldom explains low initial survival. Dormancy or near-dormancy of southern pine seedling tops seems to result from a combination of temperature, length of day (Jester and Kramer, 1939; Phillips, 1941)(___, ___), and stage of development of the stock itself. During the optimum season for planting, all three of these influences normally are such as to cause near-dormancy, but not necessarily complete dormancy. Southern pine seedlings seldom need be culled merely because the tops are in a state of active growth (p. 292).

A sudden drop in initial survival percent has sometimes coincided with a resumption of seedling growth in the nursery, notably in slash pine in Florida about 1937. But slash pine planted late in March, after the tops had not only opened their buds but had made

2 to 3 inches of new growth, has also survived extremely well, notably at Bogalusa, Louisiana, and in Jackson County, Mississippi, in the 1920's. In the 1937-38 slash pine grading study previously described, there was no consistent association between dormancy and survival (fig. 30); any effects of dormancy were overshadowed by seedling size and especially by the effects of the environments in which the different lots of stock developed.

In any event, overwinter changes in the condition of the winter buds seem characteristic of southern pine nursery seedlings; slash pine especially is likely to elongate and open existing buds and to form new ones during the lifting and planting season (fig. 22). In 1937-38 and 1938-39 studies of the effect of date of planting upon initial survival, the average survival percentages of southern pine seedlings planted at 2-week intervals during the periods November 23 through March 15 fluctuated far less than did the percentages of seedlings having visibly non-dormant tops.

Figure 32 summarizes the 1937-38 study, and shows that planting may sometimes safely be extended at least 4 to 6 weeks beyond the general breaking of top dormancy in the spring. In this study the significant variations in survival within different species during the period November 23 through March 15 were not associated with identical planting dates, nor was there any consistent association of decreases in survival with increases in percentage of seedlings having non-dormant tops. In the 1937-38 study the lowest survival for any species planted between November 23 and March 15 was 67 percent; in the 1938-39 study, the lowest for any species planted between November 4 and March 10 was 87 percent. In the 1938-39 study, longleaf survived April and late March planting conspicuously less well than did the other 3 species. Other less rigorous and comprehensive studies on the Johnson Tract and at Bogalusa, Louisiana, have given results essentially in harmony with those described.

Figure 32.--Effects of date of planting upon percentages of southern pine planting stock with visibly non-dormant tops, and upon first-year survivals, J. K. Johnson Tract, Louisiana.

Although these studies show a reasonably good chance of high survival on cut-over longleaf land in Louisiana from planting in the December 1 to March 1 season or even considerably beyond it, they give no absolute assurance. In a year of extraordinary weather conditions, severe late fall or early winter drought might reduce survival; or excessive fall rain might reduce it by lowering the physiological quality of the nursery stock (p. 290). Neither can it be expected that these results will apply exactly, throughout the lower South, on lighter, sandier soils in zones of lower spring rainfall (p. 15).

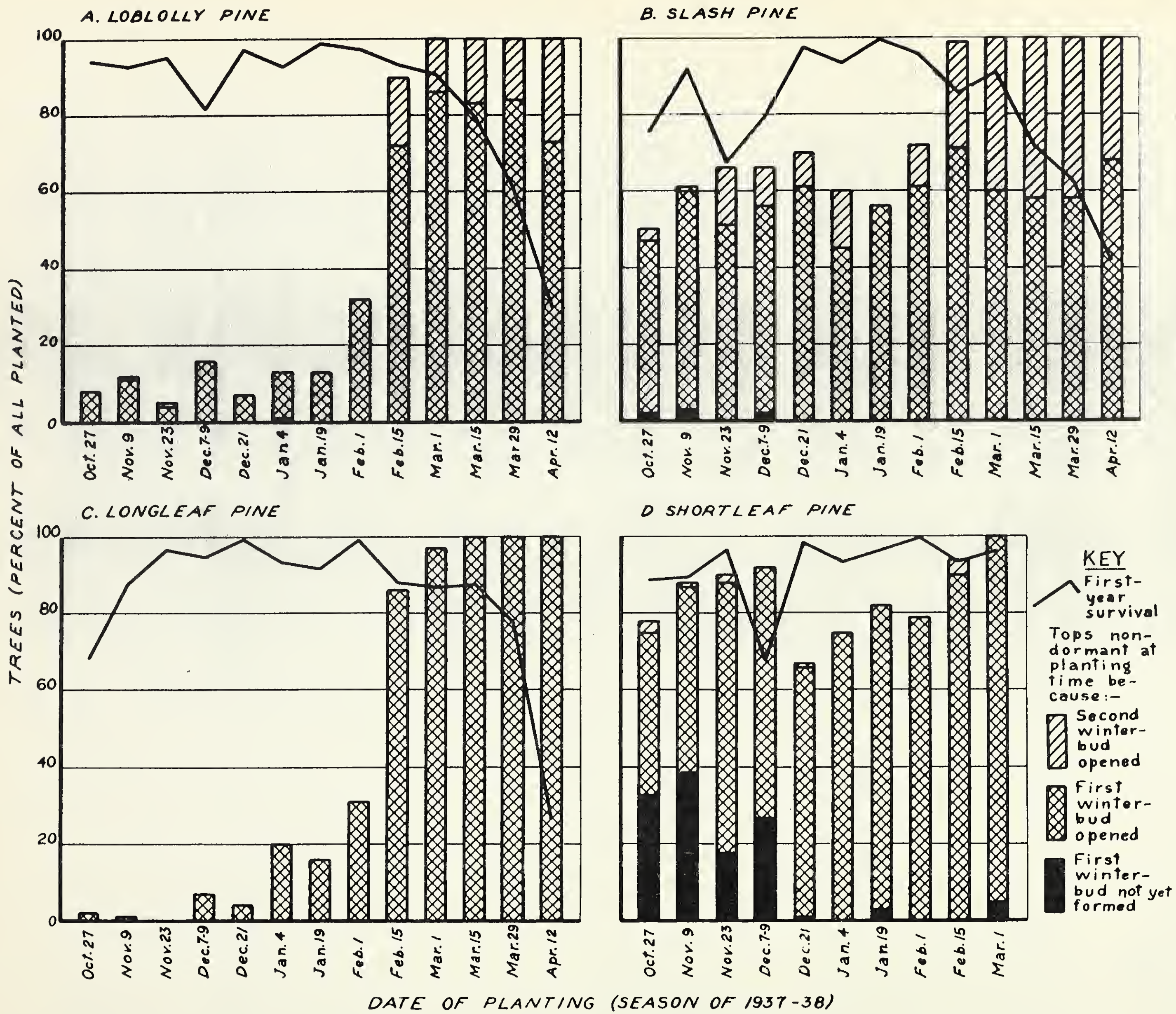

Figure 32.--Effects of date of planting upon percentages of southern pine planting stock with visibly non-dormant tops, and upon first-year survivals, J. K. Johnson Tract, Louisiana.

Under such conditions initial survival seems to fall off if planting is continued past mid-February or even mid-January (Coulter, 1946) (___)(James Fowler, Soperton, Ga., personal communication), and the optimum planting season seems to be December.

Where protracted cold weather splits the planting period into two seasons, a fall and a spring, general experience with the southern pines indicates much better initial survival from planting in the spring (Chapman, A. G., 1944; Chapman, A. G., "Strip mining," 1944; Cummings 1945; Jones, 1948; McCormick, 1948; McQuilkin, Jour. For., 1946; Minckler and Chapman, 1948)(___, ___, ___, ___, ___, ___, ___). Part of this superiority results from decreased frost-heaving, but part may result from the more prompt resumption of root growth (p. 322) after spring than after fall planting. A similar favorable development of new root tissue after spring planting has also been noted in the Lake States (LeBarron, Fox, and Blythe, 1938; Rudolf, 1950)(___, ___).

As long as weather and the physiological condition of the stock remain favorable, planting after rather than before January 15 to February 15 is likely to increase the initial survival of loblolly, slash, and shortleaf pines wherever rabbits are abundant (p. 382).

Weather During Planting

Two comprehensive direct tests on the Johnson Tract, within the normal planting periods of different years, showed no consistent, significant differences in survival as a result of planting longleaf and slash pines on sunny days, on cloudy days, just before rain, just after rain, and in the middles of long dry periods. Although not conclusive, these results suggest strongly that, within wide limits, weather at planting time is not an important cause of initial failure, and should not, without clear supporting evidence, be made an excuse for failures from controllable causes.

Considerable evidence from several localities in different years indicates, however, that freezing of the seedling roots during planting, or freezing of the ground for several or all of the first 10 days after planting, seriously reduces initial survival. This form of loss has been noted particularly with slash pine but may affect other species also. Its occurrence suggests that planting be stopped and stock be heeled-in or otherwise protected when temperatures drop below freezing or a cold wave approaches.

CONDITION AND CARE OF STOCK

The condition of the stock when planted affects initial survival as directly as does site preparation, weather, or planting method. The planter's responsibility for keeping stock in good condition from arrival until it is planted is equalled by the nurseryman's responsibility for producing seedlings of high quality and shipping them in good condition and properly packed. To detect mistakes by either the nurseryman or himself, the planter must check the condition of the seedlings both on arrival and during planting.

Root Length

Because the root-systems of 1-0 southern pine seedlings are too big to dig up, pack, or plant in their entirety at reasonable cost, root pruning is an essential part of lifting and packing. Correct root-length is therefore largely the nurseryman's responsibility. The planter should sample the stock on arrival to see that root lengths in general are satisfactory, and inspect it in more detail during planting to make sure that appreciable percentages of the roots are not too long or too short. He must also see that the roots are not broken or cut short during heeling-in or planting.

Two studies of slash and longleaf pine on the Johnson Tract have strongly confirmed the practice of pruning root systems to 7 or 8 inches for planting on cut-over longleaf pine land; of accepting seedlings with root systems snapped off as short as 5 inches; and of culling seedlings with root systems shorter than 5 inches. These studies, on somewhat different soils and in different planting seasons, gave remarkably consistent results. Pruning to 10 inches gave consistently and in some instances significantly poorer survival than pruning to 6, 7, or 8 inches 39/. Pruning to 4 inches gave

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39/ Almost identical results have been reported with guayule. In this species the number of new roots initiated on the old tap root, after lifting, was proportional to the length of the tap root, up to a limit of 7 inches, but on tap roots 9 and 12 inches long there was a significant decrease or delay in their formation (Erickson and Smith, 1947)(___). An identical pattern of new root formation may well have caused the pattern of survival of both slash and longleaf pines on good sites but without lateral roots, in table 23.

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satisfactory survival in one season but not in the other; root systems cut this short clearly cannot be depended on for good results. Pruning to 3 or to 2 inches resulted in very significantly decreased survival in both years, and also made correct planting slow and

difficult; pruning even to 2 inches, however, did not cause complete mortality. These findings are in general supported by data presented later (table 23). Experience throughout the southern pine region has shown that they are also applicable to loblolly and shortleaf pines and to a majority of southern pine planting sites.

Loss of Lateral Roots

Loss of lateral roots by breakage is one of the most frequent and important causes of low initial survival. In two studies on the Johnson Tract in different years, loss of all lateral roots very seriously reduced survival, particularly of slash pine, and of longleaf pine especially on poor (sandy or droughty) sites, regardless of how much of the tap root was retained (tables 23 and 24); it also greatly reduced the subsequent growth of such longleaf seedlings as survived (Derr, 1948)(___). Survival was high even with the greater part of the tap root removed, provided a good system of laterals was retained above the point where the tap root was cut . (table 23). Loss of only half the laterals seriously reduced the survival of longleaf pine on poor sites, and caused near-failure of slash pine (table 24).

Laterals are most likely to be lost in the nursery, but heavy losses may also occur during several phases of planting. Loss in the nursery is most likely to result from operating mechanical lifters in soil that is too dry, or at too high speed in any soil, and from careless or too rapid freeing of the roots from the earth by hand after the lifter has passed. Two very common causes of root injury during planting are vigorous instead of gentle separation of seedlings that have been packed tightly together in bales or heel-in beds, and rough removal of seedlings from a container in which they have been carried upright (fig. 34 A) instead of on their sides (fig. 34 B). Unless carefully trained and closely watched, workmen sometimes deliberately strip off lateral roots to make bar planting easier.

The most conspicuous evidence that laterals are being lost consists of masses of developing root tips, mycorrhizal rootlets, and detached whole lateral roots in the soil of the seedbed, or in packing material, heel-in beds, or planting trays. The loss is hard to detect on the seedlings themselves except by examination with a hand lens after washing. Half to three-quarters of the laterals may be removed from a previously intact root system without altering its general appearance enough so that even skilled graders will be aware of the damage.

Table 23.--Effects of lateral roots on first-year survival of planted southern pines with root systems pruned to specified lengths

Roots pruned to (inches)	Slash: Good site	Slash: Poor site	Longleaf: Good site	Longleaf: Poor site
	Survival percent			
	NO FURTHER MODIFICATION OF ROOT SYSTEM			
10	99	100	100	99
8	100	96	99	98
6	99	94	99	86
4	99	97	99	90
2	92	86	85	86
	ALL LATERAL ROOTS REMOVED			
10	38	3	60	80
8	44	1	88	63
6	56	1	78	76
4	18	2	73	45
2	22	1	36	1
	TAP ROOT PRUNED TO 3 INCHES			
8	99	99	100	91

Table 24.--First-year survival of southern pines planted on good and poor sites after removal of different proportions of lateral roots

Portion of lateral roots removed 1/	Slash: Good site	Slash: Poor site	Longleaf: Good site	Longleaf: Poor site
	Percent			
None	77	40	81	61
One-half 2/	36	24	80	39
All	6	1	42	11

1/ Entire root system pruned to 8 inches in usual manner; lateral roots, in the proportion indicated, then pruned from the main root.

2/ This treatment left enough lateral roots so that the loss would ordinarily pass unnoticed on the grading table.

Packing and Transit

Inadequate or improper packing, an obvious cause of low initial survival, has been discussed on pp.270 to 271. Even when the planter transports the stock, the nurseryman must anticipate its probable treatment in transit, pack it accordingly, and often instruct shipping agents or truck drivers how to handle it.

Drying and heating are the two principal sources of injury during transit. If the stock has been properly packed, drying need not be feared except under extraordinary circumstances. Heating, however, is an ever-precent danger whenever more than a very few thousand seedlings are shipped together. When it occurs, part of the stock is always lost outright, and the survival of the rest usually is greatly reduced. Stock which has heated in transit ordinarily can be recognized by its musty or fermented odor, discoloration of foliage or roots, often some mold, and, usually, perceptible warmth to the touch upon arrival. Precautions against heating have been given on p. 272.

Stock Storage

Even under the most favorable conditions, some stock must be stored for brief periods at both the nursery and the planting site. Bad weather and other interruptions of the planting schedule increase both the quantity stored and the duration of storage. Ordinarily the nurseryman has the better facilities for storage but the planter is better able to minimize the time any one lot of stock is stored. Heeling-in has always been a principal means of storage. The U. S. Forest Service bale (pp. 564 to 566) has also been widely used, especially for storage between receipt at planting headquarters and delivery to the local planting site. Uncertainty concerning the effects of these and other storage methods upon initial survival has, however, resulted in attributing many plantation failures to stock storage, and in specifying elaborate and often impracticable refinements of heeling-in.

During 1934-1935 through 1940-1941 more than 15 thousand seedlings, half longleaf and half slash, were stored in differently treated lots of 100 seedlings each, for various periods up to one month, in heel-ins, bales, tubs, and commercial cold storage, and out-planted on the Johnson Tract, in an attempt to get practical answers to recurrent questions about stock storage. The results showed conclusively that:

1. Stock in good condition to start with can be heeled-in safely, during the ordinary winter planting season, for periods of at least 21 to 28 days (directions for heeling-in are given on p. 562). Supplementary observations showed, however, that heeling-in for periods as long as 70 days, especially toward the end of the planting season, may seriously reduce initial survival.

2. Some widely publicized specifications for heeling-in are unnecessarily exacting; in particular, sandy soil and daily watering are not essential, and bundles of 50 or 100 seedlings need not be opened before heeling-in. In one experiment, longleaf and slash seedlings were heeled-in for 28 days in 14 different ways: with and without shelter from wind and sun; with and without artificial watering; on well-drained sandy soil, and in heavy clay flooded daily to deprive the roots of oxygen; for all 28 days in the field, and with the 28 days variously divided between nursery and field heel-ins; not only bundled, but with the test seedlings separated from the walls of the trench by an extra layer of bundles on each side. In all treatments, however, the root systems and up to 1/5 of the tops were completely covered with soil, leaving the tops at least 4/5 exposed to the air. Of the lots of seedlings stored in these various ways, the two poorest survived 89 and 90 percent respectively, and 23 of the 28 lots had initial survivals above 95 percent. The comparable random check lots from the same beds, lifted and planted the same day the stored stock was planted, survived 90 and 93 percent.

3. Stock can be stored satisfactorily in U. S. Forest Service bales for periods up to 4 weeks if the bales are kept moist and are not allowed to heat. In one study, longleaf and slash were stored for varying periods up to 29 days in 90-pound bales left on the ground, one series screened with burlap and one fully exposed to sun and wind; neither series received any water except from infrequent rains. When the bales were opened, the top 1/10 to 1/3 of the seedlings in those left on the ground for 16 to 28 days were dry; these dry seedlings were discarded without testing. The lowest survival of moist seedlings from such bales was 61 percent; the next lowest, 77 percent; moist seedlings from several bales, including one bale unsheltered for 29 days, survived better than 90 percent. In a supplementary study of longleaf stored for three weeks the bales were watered every few days; no seedlings were lost through drying and initial survival was 99 percent.

4. Even 1 to 3 days' storage in water in tubs appeared to reduce survival significantly below that of heel-in or bale storage, and longer storage in tubs was fatal. In one study, average survivals (longleaf and slash combined) were: fresh check, 68 percent; 1 day in tub, 53 percent; 3 days, 51; 7 days, 15; 14 days, 4; 21 days, 2; and 28 days, 1 percent.

Less conclusive but still noteworthy results of the 1934-1935 through 1940-1941 storage studies were:

a. Cold storage at 35° to 41° F., in small sphagnum and burlap bales, gave erratic results, especially for periods of 3 to 13 weeks. Such storage was not so thoroughly tried as other methods, or in

direct comparison with them, but seemed less reliable, as well as less convenient and more expensive.

b. Rather thorough testing in two different years showed no consistent ill effects from "double-heeling"--that is, from dividing storage between nursery heel-in and planting-site heel-in instead of heeling-in the stock in one place only for the entire period. This is reassuring, as much stock naturally has to be heeled-in at the nursery and again at the planting site.

c. There was a distinct tendency for stock that had been heeled-in for 2 to 4 weeks to survive better than stock heeled-in for only 1 to 3 days, or than unstored checks. In a few instances the superiority was very significant. To a less extent, the same tendency was apparent in stock stored 2 to 4 weeks, under favorable conditions, in bales. This finding is consistent with the good survival often obtained with nursery stock accumulated in the heel-in for 2 or 3 weeks before the shipping season. It also lends weight to the theory that prompt formation of new root tissue after planting improves survival (p. 322). (Since seedlings lifted during a period of active root growth (fig. 22) may be expected to start callusing over the pruned tips if not actually to form new roots at the point of pruning during 2 to 4 weeks' favorable storage, they presumably have a head start, in this respect, over unstored, freshly pruned lots.) The finding also supports the suggestion that root-pruning in the seed beds shortly before lifting (p. 342) may improve initial survival. Improving average survival by systematically heeling-in all stock for 3 weeks before planting should not, however, be attempted commercially until success has been confirmed by rigorous tests.

These storage studies included no tests of incomplete covering of the roots in the heel-in beds. It was felt that the harmfulness of such exposure was sufficiently proved by the root-exposure studies, and by depth-of-planting studies described later (pp. 354 to 356).

Although the studies were carried out in the Lower South, on cut-over longleaf land, with longleaf and slash seedlings only, the findings should apply generally to all southern pines and throughout the southern pine region. In the northern part, however, care must be taken to keep seedlings from freezing in bales (Anonymous, Freezing, 1938)(___).

Root Exposure

Some exposure of seedling roots to sun or wind at the nursery during lifting and packing, and in the field during distribution and planting, is unavoidable. Such exposure is never beneficial, but the emphatic warnings against even momentary exposure which appear in many

popular planting leaflets exaggerate its harmfulness to southern pine seedlings and have occasionally led to unnecessary and costly culling of good stock. So long as reasonable precautions are observed, there is little reason why short exposure during either lifting or planting should seriously reduce initial survival.

In Louisiana, exposure of longleaf and slash pine seedling roots was tested under various combinations of sunlight, temperature, and wind, in January or early February of three different years. In these three studies, exposures up to 10 or 20 minutes had little significant or consistent effect on survival. In one study, all exposures up to and including 20 minutes, regardless of degree of sunniness, gave reasonably satisfactory survivals (range, 90 to 62 percent). Beyond 20 minutes, however, survival of both species decreased seriously and fairly regularly with each successively longer period of exposure, particularly on sunny days, and exposure for 5 hours and 20 minutes on a sunny day reduced survival to 6 percent. In another study, slash and longleaf seedlings, the roots of which were exposed for 2 hours to full sun and a gentle wind on January 31, survived 48 and 67 percent; comparable unexposed checks survived 98 and 99 percent. Cummings (Cummings, Exposure, 1942)(___), who exposed the roots of 1-0 shortleaf pine seedlings for 0 to 135 minutes on a late April day, in Indiana, got a strong, smooth curve of first-year survival running from about 93 percent for 0-minute exposure to about 20 percent for 135-minute exposure.

From the results of these studies, it is recommended: (1) that effort be made to prevent the exposure of any roots to wind and sun for more than 10 minutes, especially on warm, windy, or sunny days; (2) that exposure of roots be kept as much below 10 minutes as economical handling permits; (3) that masses or piles of stock not be thrown away even if accidentally exposed for an hour or two, provided the seedlings are to be planted on the operator's own land; but (4) when stock from exposed piles or masses is being shipped, especially in small lots, that all seedlings with visibly dry roots be culled before rewetting and packing the stock. Recommendations 3 and 4 are based on observations that, in exposed piles or masses, the seedlings on top (although they themselves dry out) shelter the roots of the seedlings beneath, and that seedlings that have dried on the top of the pile can be recognized (Briggs, 1939; Cummings, Exposure, 1942)(___, ___) and removed only if they have not been rewet after exposure.

Planting trays.--To prevent exposure of the roots during hand planting, most planters carry southern pine seedlings either in 10- or 12-quart galvanized iron water pails, or, on jobs large enough to justify special equipment, in Ehrhart trays (figs. 33 and 34 B). In pails, the roots are kept wet either by water or puddling mud, or by wet moss. In Ehrhart trays, they are kept moist by a layer of wet moss beneath and a piece of wet burlap lying under the moss and

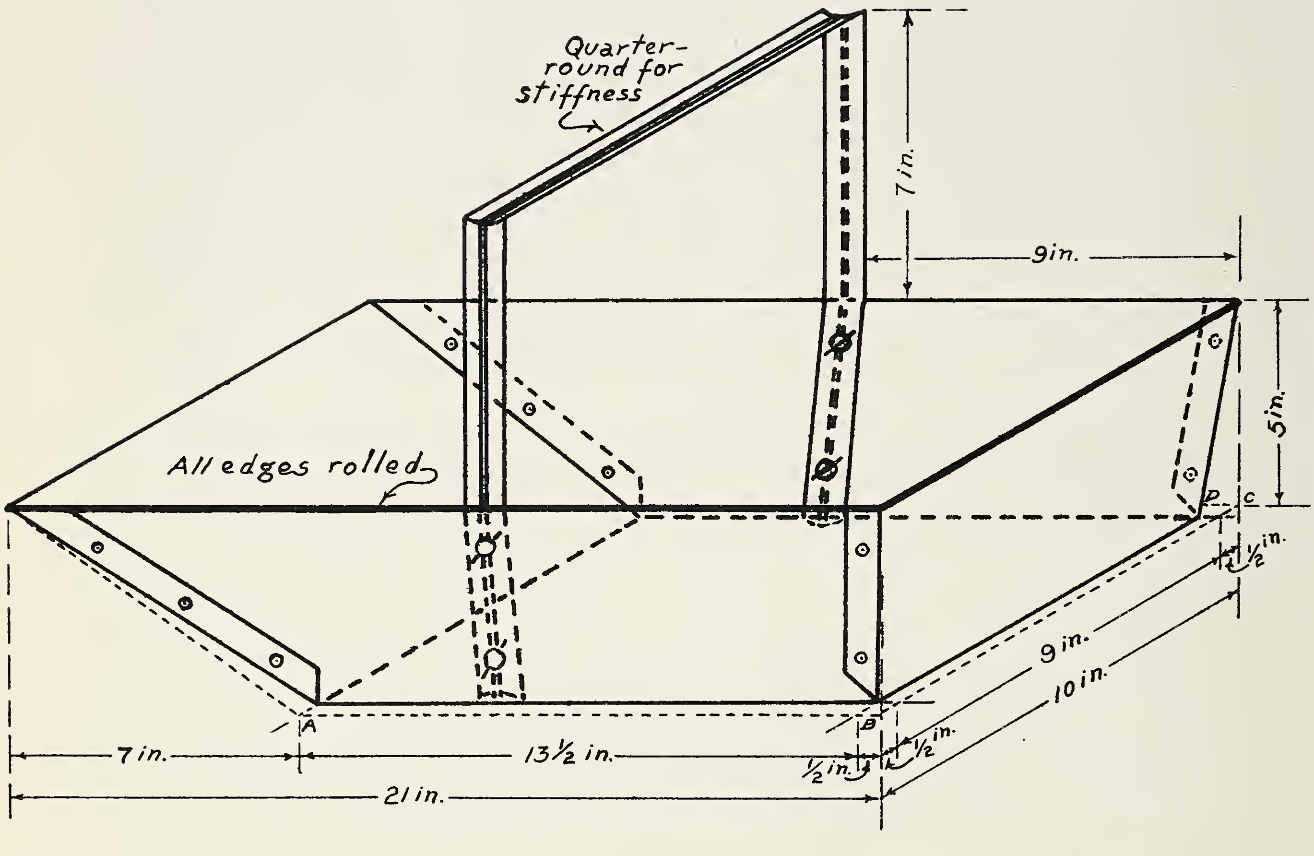

Figure 33.--Improved Ehrhart planting tray, made of 24-gage galvanized sheet steel and modified as suggested by Kellogg (Kellogg, 1936)(___), used by Region 8 of U. S. Forest Service.

extending up over the seedling roots and part of the tops. The chief advantage of the trays is that they permit carrying the seedlings flat and lifting out each seedling with minimum breakage of lateral roots. With reasonable care, many other receptables give good results (Toumey and Korstian, 1942; Wakeley, 1935)(___, ___). Planting machines come equipped with special seedling receptables or racks for standard containers. Seedlings in any type of receptable usually require additional water at intervals of an hour or less.

Figure 33.--Improved Ehrhart planting tray, made of 24-gage galvanized sheet steel and modified as suggested by Kellogg (Kellogg, 1936)(___), used by Region 8 of U. S. Forest Service.

Puddling.--This consists of coating the roots of seedlings with thin mud, about like medium-thick pea soup, before planting them. It can be done by dipping the roots in the mud and then carrying the trees in a tray of wet sphagnum moss, but is more often done by carrying the trees upright in a pail of the puddling mud. When moss is unavailable, the mud does perhaps keep the roots more uniformly moist than does plain water. Puddling makes the trees unpleasant to handle, however, and means carrying more weight. Since it involves an extra operation, it adds to costs.

Planting instructions and circulars contain many contradictory and some extreme statements about puddling. Some pronounce it essential. Some say it kills the seedlings, a few attributing death to "chafing off of the root hairs" (p. 235) by the puddling mud. In studies on the Johnson Tract in two different years, puddling of two species in sharp quartz sand, in subsoil clay, in a mixture of sand and clay, in fertile top soil, and in a sand-clay mixture inoculated with chopped mycorrhizal rootlets, increased survival significantly in only one minor instance, and decreased it significantly in none. In practice, puddling still is widely used in farm planting, but seldom in large-scale operations. Since unpuddled seedlings survive satisfactorily, puddling is judged unnecessary, except possibly where moss cannot be obtained to keep the roots moist during planting.

Mechanical Injuries During Planting

Except for breakage of lateral roots, which has already been discussed, mechanical injuries to seedlings during planting (including damage by workmen walking carelessly over newly planted areas and by the packing wheels of planting machines) consist mostly of (1) stem-bending, (2) crushing, (3) bark-scraping, (4) root-scraping, and (5) splitting of main roots.

Repeated tests have shown that these 5 types of injury reduce initial survival very little. In rigorous studies, even stepping hard on every tree immediately after planting did not significantly reduce the initial survival of either longleaf or slash pine. Moreover, in routine planting, all such injuries are relatively infrequent.

Two studies on the Johnson Tract in different years demonstrated clearly, however, that a combination of two or more types of injury, each negligible in itself, was likely to cause a serious reduction in initial survival. This was as true of minor mechanical injuries as of serious root exposure, loss of laterals, or certain serious errors in planting discussed later. The results of these studies are a strong argument against taking chances with any form of injury in either nursery or field, lest the effect of an avoidable injury aggravate the effect of a later unavoidable one.

Special Conditioning of Stock

When initial survival is low despite correct application of established nursery and planting practices, the question naturally arises as to whether some special treatment of the stock before it leaves the nursery would improve results. Although none has been developed to the point of commercial application in the South, 5 such special treatments deserve mention. They are: (1) root-pruning in the seedbed, with a period of growth between pruning and lifting; (2) fertilization between the end of the growing season and lifting; (3) use of foliage coatings to reduce transpiration immediately after planting; (4) needle pruning to reduce transpiration immediately after planting; and (5) root inoculation or treatment of the seedlings with growth-promoting substances or other chemicals to improve root formation after planting.

Root pruning in place, an appreciable time before lifting, offers some promise of success (Hastings, 1923; Soc. Am. For., Com. Tech. Prac., 1932)(___, ___). The feasibility of so pruning southern pine seedlings, by means of a special blade on the mechanical lifter, has been demonstrated for all but very heavy nursery soils. June, July, or August root pruning of slash, longleaf, and shortleaf seedlings has produced no substantial benefits (Huberman, Jour. For., 1940)(___), but theoretical considerations (fig. 22) (Chadwick, Root pruning, 1946)(___) and the results of one preliminary study suggest that more benefit may result from late-season than from summer root pruning in place. Root pruning at 6 to 7 inches, 4 to 8 weeks before scheduled lifting, with undercutting at 10 to 11 inches at lifting time, seems worthy of small-scale trial. Dangling laterals of seedlings would still require pruning to 7 or 8 inches at the grading table.

Although excessive late-season fertilization, especially with nitrogen, seems to produce succulent stock that survives poorly, light to moderate applications of mineral nutrients from September or October to 5 weeks before lifting give promise of increasing initial plantation survival. Preliminary studies suggest that, for such late applications, fertilizers with a high ratio of potash to nitrogen are most likely to be beneficial. Such treatments are worth small-scale trial, particularly in nurseries the stock from which survives poorly, or for the production of stock for unusually adverse sites.

Some fungicidal foliage coatings increase transpiration; others decrease it (Foster and Tatman, 1940; Horsfall, 1945; Horsfall and Harrison, 1939)(___, ___, ___). An otherwise unsuccessful rabbit-repellent spray has been found to increase initial survival of planted slash pine, and the initial survival of planted longleaf has been significantly altered by varying the sticker applied with Bordeaux mixture at lifting time. Presumably these sprays affected survival through their effects on transpiration. Foliage sprays or dips to increase initial survival by reducing transpiration immediately after planting have been developed commercially (Gardner, 1948; Thomas and Stadel, 1948)(___, ___), and are used in transplanting ornamentals (Marshall and Maki, 1946)(___). Applications of some sprays to forest tree seedlings for this purpose have been ineffective or harmful (Hartley, 1935; Shirley and Meuli, 1938)(___, ___). S/V Ceremul C, however, is reported to have increased initial survival of planted ponderosa pine (Thomas and Stadel, 1948)(___), and both lanolin-monoethanolamine stearate and commercial Dowax have been reported to reduce transpiration and increase survival of planted loblolly, longleaf, and other pines (Marshall and Maki, 1946; Ostrom, 1945) (___, ___)(and unpublished data). Further testing of foliage-coatings for southern pine seedlings is justified, especially where the stock must be planted in areas of low winter or early spring rainfall (fig. 4) or on excessively droughty sites.

Because most of the foliage of longleaf seedlings may be cut off with a mowing machine without injuring stems or buds, it is frequently proposed that it be pruned just before lifting, to reduce transpiration and increase initial survival, especially on dry sites. Several large-scale tests of close pruning of the needles have resulted in lower survival of pruned than of unpruned longleaf seedlings. In two rigorous experiments, complete defoliation of both longleaf and slash seedlings at or before lifting time has significantly reduced survival, and the more seriously the earlier the pruning was done, up to 12 weeks before lifting (unpublished data). Removing half of the total number of needles, however, up to 12 weeks before lifting, either did not affect the survival of longleaf and slash seedlings, or improved it. Several small unpublished studies (including one by Bailey Sleeth, Bureau of Plant Industry, Soils, and Agricultural Engineering) suggest that cutting off only the outer portions, up to three-quarters, of all longleaf needles, instead of whole needles as in the earlier tests, may similarly increase initial survival.

Various concentrations of indoleacetic acid, indolebutyric acid, naphthaleneacetic acid, and related growth-promoting substances applied to the roots or tops of southern and other pines in a number of studies have in general failed to improve survival, and in several instances have reduced it (Avery, Johnson, Addoms, and Thomson, 1947; Fowells, 1943; Maki and Marshall, 1945; Ostrom, 1945; Way and Maki, 1946)(___, ___, ___, ___, ___). Plank has reported improved survival of planted slash pine seedlings as a result of treating the roots with indolebutyric acid (Plank, 1939)(___), but a Chi-square analysis of his published data shows that, because of the small numbers of seedlings tested, the improvement can hardly be considered significant. In two rigorous studies on the Johnson Tract, in different years, no significant changes in the survival of slash or longleaf pine seedlings were produced by treating the roots with commercial preparations of indolebutyric acid, or with potassium permanganate solution or dilute sodium nitrate solution, or by puddling the roots in mud containing chopped mycorrhizal rootlets (unpublished data). In one of these studies and in an earlier study (Howard Lamb, personal communication) the application of commercial fertilizers in the puddling mud or in a flour paste, even at such low rates as 0.6 gram of 6-10-7 fertilizer per tree, killed 66 to 99 percent of the seedlings within 48 hours after planting.

PLANTING METHODS

In choosing planting practices for local conditions, the planter should keep three general rules in mind.

First, practices and techniques should be accepted or modified only to the extent that their influence on initial survival permits. Some, like depth at which the seedling is set, affect survival directly and significantly; these permit little range of choice or modification. Others affect survival very little; tools for hand planting, for example, may be chosen primarily to keep costs low rather than for their effects on survival.

Second, in choosing or modifying practices and techniques, the planter should realize that some are much easier to control than others. In hand planting, for instance, he can control depth of setting almost perfectly, but in machine planting control of depth is difficult.

Third, in cases of doubt about the effects of planting methods and techniques on initial survival, their probable effects on the water intake and water losses of the planted seedlings should always be considered (p. 321).

Hand Versus Machine Planting

Before World War II, all commercial planting of bare-rooted southern pine nursery seedlings was with hand tools. Hand tools must still be used on many eroded, steep, rocky, brushy, or partly stocked sites, and may always be more economical than machines for small-scale planting under certain conditions. On vast acreages, however, especially of cut-over longleaf pine land and of abandoned but ungullied old fields, machine planting is feasible and is likely to be cheaper than hand planting. In Florida, for example, about 6 million acres, or 85 percent of the total plantable area in 7 forest types, has been reported as plantable by machine (McCormack, 1949; McCormack, 1949; McCormack, 1950; McCormack, 1950)(___, ___, ___, ___).

Advances in design have made machine planting practicable in the southern pine region only since 1946. Since new machines are constantly being developed, it is inadvisable to attempt a discussion of machines and their operation here; details should be obtained from the rapidly growing literature on the subject (Brender and Cooper, 1949; Davis, J. E. 1947; Emerson, 1946; Hardee, 1948; Hopkins, 1949; Hoskins, 1947; Jones, 1948; Knapp, 1945; Knapp, "Gair," 1946; Knapp, "Valdosta," 1946; Smith, McClain B., 1949; Stevens and Bell, 1945; Stevens and Bell, 1946; Trenk, 1944; Trenk and Bruhn,1947; and later publications)(___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___, and later publications). Machine-made holes or

slits in which trees may be planted by men on foot (Powell, 1948; Weaver and Fishel, 1944)(___, ___) are another possible means of reducing planting costs.

Exhaustive studies of hand planting give every reason to expect as good survival from machine planting, provided that the machine used is adapted to the site in question (Smith, McClain B., 1949)(___) and the seedlings are set at the correct depth. The initial and fourth-year survivals of slash and longleaf pines in the earliest recorded test of machine planting in the South (Ericksson, 1939)(___), with machines now outmoded (Smith, McClain B. 1949; Toumey and Korstian, 1942)(___, ___), were comparable to those of hand-planted checks. In later studies, machine planting has resulted in nearly as good survival as hand planting, and sometimes better (Anonymous, "Tree planters," 1947; Hardee, 1948; Muntz, SFN 57, 1948; Smith, McClain B., 1949)(___, ___, ___, ___). The chief obstacle to high survival in machine planting usually is the difficulty of setting the seedlings at the right depth (p. 354). Most planters allow for losses from this cause by planting one or two hundred more trees per acre by machine than by hand; the saving effected by machine planting more than offsets the cost of the extra trees.

Ball planting (p. 49), under certain ideal conditions an alternative to planting bare-rooted nursery stock, ordinarily results in very high survival.

Rates of planting by different methods are discussed on pp. 371 to 372.

Choice of Hand Tool

Survival studies have shown conclusively that the hand tool for planting southern pines may safely be chosen on the basis of labor efficiency. Systematic time studies and general experience have shown that, under most southern conditions, a wedge-bladed metal bar weighing about 10 pounds is the most efficient tool. In particular, studies of more than 4,000 trees planted on cut-over longleaf land during 1924-25 through 1935-36 showed that mattocks gave no better survival than bars, if as good, and were much slower; later tests (Ericksson, 1939)(___) have confirmed these results. By far the greatest part of all southern pine nursery stock has been planted in slits made with bars (fig. 34). So far as is now known, mattocks, post-hole diggers, or special planting tools need be substituted for planting bars only on certain stony, badly eroded, or very heavily vegetated sites on the borders of the southern pine region and in limited localities within it (Chapman, A. G., 1944; Cummings, 1945; Gemmer, 1933; Hendrickson, 1945; Limstrom, 1948;

McCormick, 1948; Meginnis, Jour. For., 1933; Minckler and Chapman, 1948)(___, ___, ___, ___, ___, ___, ___, ___).

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Figure 34.--Hand planting of southern pines with: A, old-style stepless bar, men working in pairs, and trees carried in water in 12-quart pail; and B, modern bar with step, "half-Z" handle (see fig. 35), each man working independently and carrying his own trees in wet sphagnum moss in Ehrhart tray.

Apprehensions concerning adverse effects of slit planting on later survival and growth (Kroodsma, 1939; Rudolf, 1939; Rudolf, 1940; Schantz-Hansen, 1945; Wilde and Albert, 1942)(___, ___, ___, ___, ___) seem unwarranted so far as bar-planted southern pines are concerned. Excavations of roots, and the evident vigor and thrift of thousands of acres of plantations already yielding pulpwood and naval stores, argue against any great lurking danger from bar planting these species.

Two models of the planting bar, developed from earlier models with less satisfactory "D" handles and often without steps, have been in general use since about 1936. They are manufactured commercially (fig. 35) with an offset attachment of handle to blade, the patent on which is held by the Council Tool Company. Their essential features, in addition to rigidity, strength, and an optimum weight of 10 pounds, are: a blade 10 inches long, 3 to $3\frac{1}{2}$ inches wide, 3/4 inch thick at the upper end, with high-quality steel edge (square or rounded as preferred) and smooth finish; adequate but not unduly protruding grip and step; and convenient length. For planting in pairs, most workmen prefer "T"-handled bars 42 inches long; very tall workmen prefer 45-inch bars. For planting by each man independently, 42-inch "T"-handled bars are reasonably satisfactory, but 36-inch "T"-handled bars are better and 38-inch "half-Z"-handled bars are best. Despite published information (Toumey and Korstian, 1942; Wahlenberg, 1946)(___, ___) to the contrary, the open end of the "half-Z" handle should be on the same side of the bar as the step, as in figs. 34 B and 35, to avoid snagging the planter's clothes.

Figure 35.--Commercially manufactured bars for planting southern pine seedlings (Council Tool Company patent). A. With "T" handle, for use by men working either in pairs or independently. B. With "L" or "half-Z" handle, for use by men working independently.

A steel dibble, 17 inches over all, with a pistol grip, and weighing 5 pounds (Gemmer, 1933)(___) is excellent for planting by men carrying and setting their own trees in heavy brush on deep, coarse sands. It is inferior to a bar on heavier soils and more open sites, and has not come into general use. On most sites a shovel or

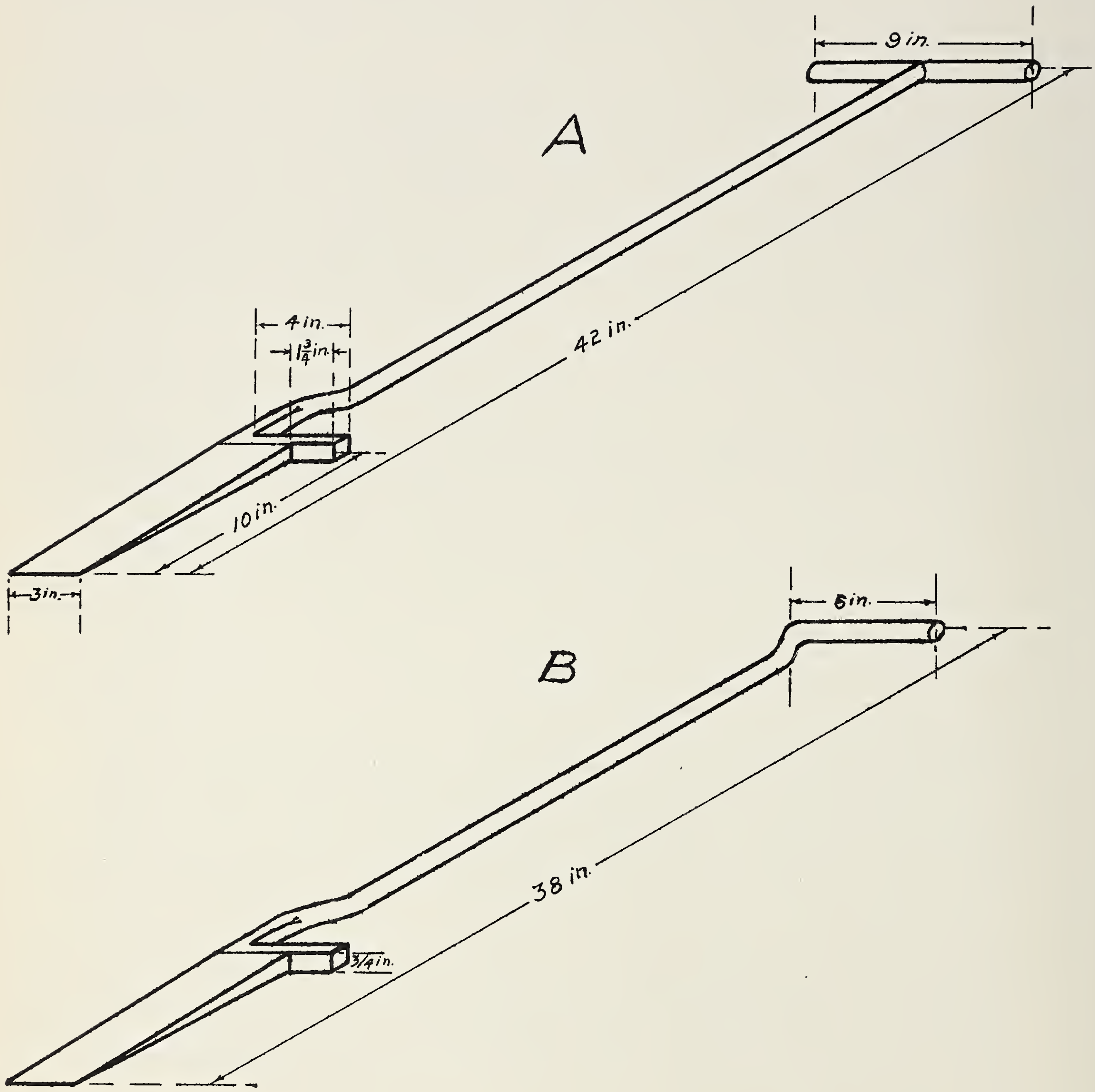

Figure 35.--Commercially manufactured bars for planting southern pine seedlings (Council Tool Company patent). A. With "T" handle, for use by men working either in pairs or independently. B. With "L" or "half-Z" handle, for use by men working independently.

any other tool that will make a slit permits planting nursery stock with good survival, although with less efficiency than does a bar.

On sites too stony or hard for bar planting, or when bars are unavailable, mattocks or grub hoes generally are used for planting southern pines. The chopping blade of the mattock seldom is needed, and a grub hoe with a 4-pound head and a blade 9 or 10 inches long is about right for most conditions. Most mattock or grub-hoe blades curve too much toward the handle for easiest planting, and can advantageously be straightened until the cutting edge comes only ½ inch above a level surface on which the rim of the eye lies flat. A grub hoe designed especially for tree planting is described in (Anonymous, Hoe, 1948)(___).

For ball planting, one useful tool is the Council Special Seedling Lifter and Transplanter 40/. This tool (Toumey and Korstian,1942, p. 470)(___, p. 470) consists of a slit steel cylinder, mounted on a handle with a "T"-grip and a treadle. The cylinder is forced into the ground and contracted with the treadle. The tool is then withdrawn with a plug of soil about 5 inches in diameter and 6 inches long, weighing from 4 to 8 pounds. The tool works best in soil neither very heavy nor very light, and moist enough so that the plug holds together when released from the cylinder. Horton (Horton, 1936)(___) describes and illustrates an ordinary square-pointed, short-handled garden spade with the two halves of a round-pointed shovel welded to the sides of its blade for similar ball planting.

40/ Manufactured by the Council Tool Company, Wananish, North Carolina.

Planting with Bar or Mattock

Debated alternatives in bar-planting have included: (a) setting the tree upright by the standard method (p. 567) versus making the planting-slit at a 45-degree angle and closing it by stepping on it; (b) in the standard method, setting the tree in the center of the slit, or in the corner (which is alleged to give better control of depth of setting); and (c) planting with men working in pairs or with each man working independently and carrying and setting his own trees. Slant planting has been advocated as economical, and opposed as likely to cause serious mortality and to deform the roots of surviving trees; Münch's results in Europe, however, seem to refute the latter arguments (Münch, by Baldwin, 1934)(___). Setting the seedling in the corner of the slit has been advocated as making planting more rapid and uniform, and opposed (without evidence) as reducing survival and distorting the roots of the survivors.

In mattock-planting the debatable alternatives have been center-hole, side-hole, and slit-planting (pp. 570 to 574), of which center-hole is the slowest and slit-planting the fastest. Center-hole planting permits spreading the roots well, and has been both advocated and condemned because it leaves the roots in contact only with soil which has been loosened in preparing the hole; one school of thought considers side-hole and slit-planting better than center-hole because they leave the roots at least partly in contact with soil in which undisturbed structure still permits capillary movement of water. Mattock-slit planting, however, like bar-planting, is charged with killing or injuring trees by compressing their roots in one plane.

In two rigorous studies on the Johnson Tract, in different years, all these variations of bar and mattock planting were tested, with both slash and longleaf pine. The average initial survival did not differ markedly from tool to tool, nor was there any marked superiority or inferiority of initial survival from method to method of using either tool. Although the point has not been checked by excavating roots, none of the methods of using either tool has produced any discernible signs of abnormal growth or of lack of windfirmness during the first 10 years after planting. Negligible differences in initial survivals following center-hole and side-hole mattock planting of loblolly and shortleaf in the Georgia Piedmont have been reported (Hendrickson, 1945)(___). Evidently the method of using the tool, as well as the tool itself, may safely be chosen for maximum labor efficiency rather than for its effect on initial survival. The most efficient, in the vast majority of cases, is bar planting with each man carrying and setting his own trees.

Opening and Closing the Slit in Bar Planting

Failure to close the top of the planting slit greatly reduces initial survival. Except for wrong depth of setting (discussed later) it is likely to be the most frequent and serious error committed in bar planting. The importance of other errors in opening and closing the slit have been somewhat over-emphasized (Wakeley, 1929; Wakeley, 1935; Wakeley, 1938)(___, ___, ___). Both rigorous studies and the good survival obtained in much routine planting have shown that most of these errors cannot possibly affect initial survival as adversely as was formerly thought, and that extreme care to avoid them may greatly increase costs without improving results.

Serious decreases in initial survival have been attributed to: (a) opening the planting slit too widely (making "hour-glass-shaped" slits, alleged to prevent proper closure and to leave fatal air-spaces around the roots); (b) allowing leaves, grass, and other trash to get into the planting-slit; (c) closing the planting-slit without straightening out the seedling roots ("planting with U-roots," popularly but erroneously believed to be the principal cause of plantation mortality); (d) failure to close the bottom of the planting-slit

completely; (e) failure to close the top of the planting-slit completely; and (f) making the closing-slit too close to the planting-slit or failing to fill the closing-slit by means of a second closing-slit or a thrust with the heel.

The effect of each of these "errors" in bar-planting technique, except b, was tested on the initial survival of longleaf and slash pine on the Johnson Tract, in from one to three rigorous studies apiece. Results of "incorrect" planting were compared with those of correct, standard two-man-crew bar-planting, with a single closing slit about $3\frac{1}{2}$ inches behind the planting slit and the closing slit in turn closed with the heel. The soils on which these tests were made were moderately stiff, especially at the bottoms of the slits, and therefore might be expected to accentuate any adverse effects of improper planting (Schantz-Hansen, 1945)(___). In all treatments the seedlings were set at the same depth as that in which they had grown in the nursery. Table 25 summarizes the initial survivals resulting from the different types of faulty planting and from correct planting of checks in two of these studies, in different planting seasons. In a study in 1934-35, slash survived 69 percent when planted with U roots; 65 percent when no closing-slit was used, the top of the planting-slit was closed with the heel, and the bottom was left unclosed; and 62 percent with standard bar planting. With longleaf in the same study, each of these 3 treatments resulted in 86 percent survival. In these three studies contrasts among treatments are valid only within each planting season.

Despite some inconsistencies, particularly in the 1935-36 study, these results show several important things.

1. Exaggerated or "hour-glass" opening of the planting-slit by excessively working the bar handle back and forth, although it wastes time and effort, is an unimportant cause of poor initial survival.

2. Planting with U-roots, far from causing certain death as has sometimes been charged, usually has a negligible effect on initial survival. In these studies, it gave survival about as good as or better than the average survival of comparable checks in five cases out of six. This is not to condone planting with U-roots, or to deny that such planting may later increase windthrow (p. 377), but it does suggest looking for more likely causes when survival is poor. It is not illogical to assume that U-root planting may sometimes slightly increase survival by keeping all roots in contact with the best topsoil. Rudolf similarly reports little reduction in survival from U-root planting in the Lake States, and notes that the greatest amount of moisture, over a 7-year period, was in the top 6 inches of soil (Rudolf, 1939; Rudolf, 1940)(___, ___).

Table 25.--Effects of slit opening, root placement, and slit closure on initial survival of bar-planted southern pines

Treatment 1/	1935-36 study		1936-37 study	
	Slash	Longleaf	Slash	Longleaf
	- - - Survival percent - - -			
Standard 2-man-crew bar-planting	2/ 71	3/ 42	96	82
"Hour-glass" (excessively opened) slit, but well closed with bar and heel	73	42	87	89
U-roots 4/ in normal slit	56	42	94	88
Closing-slit within 1 inch of planting-slit; heel not used	70	38	89	81
Slit closed at top only, with bar; heel not used	68	51	86	51
Slit closed at bottom only, with bar; heel not used	76	21	57	35

1/ Roots normally placed in slit in all treatments except specific test of U-roots.

2/ Average of 3 check treatments surviving 63, 78, and 71 percent.

3/ Average of 3 check treatments surviving 39, 54, and 34 percent.

4/ Roots doubled in the middle and left with the pruned ends pointing upward after planting, though not projecting above ground.

3. The relatively high survival of all four lots of seedlings planted with a closing-slit only 1 inch from the planting-slit, and without filling this closing-slit by forcing earth in with the heel, shows that a second closing slit is an unnecessary refinement. In bar planting at 6- by 6-foot spacing, making a second closing slit requires at least 2,400 waste motions per acre.

4. Incomplete closing of the bottom of the planting-slit, although in the 1936-1937 study it decreased survival of both species and especially of longleaf below that for four other treatments, did not decrease survival significantly in the other two studies. These results have important bearings on both hand and machine planting. They show that no time-consuming special precautions need be taken to close the bottom of the planting-slit in bar or mattock planting; following the directions on pp. 567 to 574 insures sufficient closure. They also show that very firm packing of the soil against the bottom of the root system is not essential to successful machine planting. In the earliest test of machine planting in the South it was noted that the machine packed the earth less firmly than did hand tools, yet machine planting gave fully as good survival (Ericksson, 1939)(___). Modern machines, although sometimes criticized for insufficiently firm packing, have also given as good survival as hand tools.

5. Failure to close the top of the planting-slit reduced very significantly the average survival (both species combined), in both years this faulty technique was tested, even though slash survived it fairly well in 1935-1936. With longleaf, leaving the top of the planting-slit open caused near-failure in 1936-1937 and failure in 1935-1936. In the 1935-1936 study it was the only fault which reduced average survival (both species combined) below the range of similar average survivals of check lots planted correctly and exactly alike (table 25, footnotes 2 and 3). In the 1936-1937 study it again resulted in much lower survival than any other fault. Unlike the others, therefore, it must be counted a serious error. By the same token, a planting machine that fails to close the soil firmly against the top of the seedling roots must be regarded with suspicion.

Reexamination of the trees in the 1935-1936 study 4½ growing seasons after planting showed that longleaf survivals had decreased below those in table 25 by from 4 to 9 percent, and slash survivals by from 2 to 13 percent. There was no consistent relationship between decrease in survival and error in planting technique, and nothing to indicate any serious effect on survival after the first year as a result of any of the planting faults studied. It should be remembered, however, that the faults other than the failure to close the top of the planting-slit might still affect survival after the first 5 years in plantation, or reduce wind-firmness, or cause root infection (Hepting and Downs, 1944; Rudolf, 1937; Rudolf, 1939; Rudolf, 1940) (___, ___, ___, ___). These errors in planting technique should

therefore be avoided as far as possible without increasing the cost of planting.

Depth of Setting

In ordinarily well-conducted planting operations, setting southern pine seedlings at the wrong depth probably reduces initial survival more often and more seriously than any and all other errors in planting technique combined.

Seedlings should be planted at the same depth as that at which they grew in the nursery--that is, with the nursery ground line at the surface of the soil of the planting site. (With all southern pine seedlings except longleaf, a distinct change in color, from dull green above ground to yellowish-brown below ground, marks the position of the root collar or nursery ground line; with longleaf, the under side of the lowest needles may be taken as the ground line.) The surface around the newly planted tree should form neither a mound nor a hole (Minckler and Chapman, 1948)(___), especially in bare, freshly burned, or easily eroded surfaces. One of the chief disadvantages of furrowing as a means of site preparation is that furrows are likely either to wash out or fill in after the trees have been planted.

If seedlings cannot be planted at exactly the same depth, planting them a fraction of an inch deeper than they stood in the nursery is preferable to setting them too high; some authorities say $\frac{1}{4}$ inch deeper (Minckler and Chapman, 1948)(___), or up to 1 inch in special cases (Cummings, 1945)(___). Overdeep setting in general is thought to increase root and root-collar infection (Hartley, 1935)(___). The practice of setting longleaf seedlings approximately $\frac{1}{2}$ inch higher than they grew in the nursery to prevent silting (Toumey and Korstian, 1942; Wakeley, 1929, 1935, and 1938)(___, ___, ___, ___) generally does more harm than good, and should be abandoned.

These recommendations are supported by wide experience with all species and by rigorous experiments with both longleaf and slash pine, in each of two different years, on the Johnson Tract. In these studies there were few significant differences among the initial survivals of seedlings set at nursery depth or deeper, but almost without exception, the initial survival of seedlings set $\frac{1}{2}$ inch too high, or higher, was significantly or very significantly reduced (table 26). (Except for higher mortality among seedlings set more than 1 inch deep, a subsequent study of both hand-and machine-planted trees confirmed exactly the relationships shown for longleaf in table 26 (Smith, McClain B., 1949)(___).) The high initial survival of some of the deeply set seedlings must be accepted with reservations, because of the possibility of a delayed adverse effect of deep setting, particularly of longleaf pine. The bad effects of setting seedlings too high are beyond question. With most lots of seedlings set more than 1 inch too high, these effects amounted to plantation failure. In these and parallel experiments, slight differences in depth of setting produced far greater differences in initial survival than any

Table 26.--Effect of depth of setting on first-year survival of bar-planted southern pines

Treatment 1/	1935-36 study: Slash	1935-36 study: Longleaf	1936-37 study: Slash	1936-37 study: Longleaf
	Percent surviving			
Seedlings set deeper than they grew in the nursery, by--				
2 inches	83	80	95	82
$1\frac{1}{2}$ inches	80	70	98	83
1 inch	80	82	96	95
$\frac{1}{2}$ inch	81	83	96	90
Check: set at same depth as in nursery	83	73	92	74
Seedlings set higher than they grew in the nursery, by--				
$\frac{1}{2}$ inch	58	44	91	59
1 inch	35	34	78	56
$1\frac{1}{2}$ inches	23	10	56	40
2 inches	26	7	59	30

1/ Root systems pruned uniformly to $7\frac{1}{2}$ inches before planting; planting slits closed in normal manner.

details of bar planting except failure to close the top of the planting slit (table 25).

It is thought that the main cause of mortality in high setting is loss of water through exposed root tissue. This seems a more likely explanation than insufficient depth of root tips. In the two studies just described, for example, the seedlings were root-pruned to $7\frac{1}{2}$ inches. The four lots set 2 inches too high therefore had their root tips $5\frac{1}{2}$ inches below the soil surface. Their average initial survival was 30 percent. Essentially comparable stock was planted under parallel conditions in two studies of root-pruning. Four lots of these seedlings root-pruned to 5 inches had their root tips $\frac{1}{2}$ inch less far down than the four lots set 2 inches too high, but, being set with their root-collars at ground level, had no root tissue exposed, and had an average initial survival of 56 percent.

Since depth of setting has these important effects on survival and the greatest single difficulty in correct machine planting has been in setting the seedlings at the right depth, efforts to improve both design and operation of planting machines should be concentrated on setting the seedlings at the depth at which they grew in the nursery, or (table 26) slightly too deep rather than too high.

Skill of Individual Planter

Lack of planting skill, although it undoubtedly reduces initial survival in many cases, is far less of an obstacle to success than is often assumed. In the first place, the blank or nearly blank rows frequently attributed to poor planting by individual workmen are as likely to have resulted from injury to particular bundles of stock during lifting or storage, or from the depredations of a hog or rabbit traveling systematically down a row. Secondly, individual deficiencies in planting ability can almost invariably be overcome by training and supervision.

Two rigorous experiments on the Johnson Tract, in different years, revealed no significant differences in the survival of longleaf and slash seedlings planted by different men who had been equally well trained in correct planting (pp. 567 to 569). It was also found, in studies of the effects of faulty planting upon survival, that it is hard for well trained, experienced men to plant incorrectly even if they want to.

Fertilizing the Planting Spot

There has been much speculation about the desirability of fertilizing the planting spot, but few reports of its effects on initial survival, particularly of southern pines, have been published. McQuilkin has reported decreased frost-heaving, but also increased weed-growth and decreased survival of

planted red pine (especially of small seedlings) as a result of fertilizing planting-spots (McQuilkin, Jour. For., 1946)(___). Others have noted reduced survival of shortleaf and other pines (either from increased competition by weeds or from direct injury by the fertilizer) without attendant reduction in frost-heaving (Cummings, 1941; Holsoe, 1941; Wilde, Trenk, and Albert, 1942)(___, ___, ___). The closing-slit in standard bar-planting offers an easy method of fertilizing the individual tree, but even this involves considerable expense for fertilizer and labor, and should not be tried on a large scale until thorough testing has shown benefits in proportion to costs.

Even if it increased initial survival significantly, fertilization sufficient to increase early growth of planted loblolly and slash pines probably should be avoided in zones of serious fusiform-rust infection (p. 394).

Control of Spacing

In most planting in the southern pine region, control of the spacing chosen (pp. 38 to 46) should not be maintained so closely as to increase greatly the cost of planting, but merely well enough to avoid wasting growing space or overcrowding the planted trees. Exceptions are demonstration and experimental plantations, in which precise spacing and alignment are desirable or essential, and plantations in brush or on eroded land, in which control of spacing must be worked out to fit local circumstances.

In hand planting on unprepared or on burned sites, some planters rely entirely on the skill of the workmen to keep rows reasonably straight and uniformly spaced. Others maintain the direction and width of the planting strip more exactly by lining up flags in front of both the first and the last man in the planting line, leaving the men between to space their rows by eye. Crews of 12 to 20 men (the number increasing with the skill of the men and the openness of the site) can plant at satisfactorily uniform spacing with two rows of flags. On the less brushy sites, it has been found possible to keep almost equally good spacing by using only one line of flags, set to mark the new row next to the last one planted on the preceding strip. When the site is prepared by furrowing, flags are seldom needed, as each successive furrow is spaced by eye, with occasional check measurements, from the preceding one. When spots are scalped in advance of planting, the flags are used by crews preparing the spots. On unprepared sites, some planters have their crews plant abreast. Region 8 of the U. S. Forest Service has found it quicker to have the crew move down the strip at an angle of 45 degrees, the lead man planting on the flag line, and the man on each succeeding row planting one space farther back (U. S. Forest Service, 1939) (___). The faster workers should always be at the forward end of the crew.

Regardless of the method of keeping the rows straight and well placed, the distance between trees within each row is kept by pacing, checked occasionally with a measuring stick. Trees in adjacent rows need not be directly opposite each other; location with respect to good or bad planting spots or already established seedlings is often better if they are not. An exception is planting in equilateral triangles (p. 46), in which control of spacing is maintained by planting trees squarely opposite each other in rows twice as far apart as the specified distance between rows. On the return trip the crew completes the triangles by planting a tree in the middle of each of the rectangles formed by the trees planted on the way out.

Where seedlings, saplings, or larger trees are already established, the specifications of Region 8 of the U. S. Forest Service for hand planting at 6 by 6 spacing are essentially as follows: (a) in approaching a pine seedling or small sapling already established on or within 3 feet of the row, plant the last spot before it if the spot falls more than 3 feet from the established pine; if it falls within 3 feet, do not plant; (b) in either case, plant the next seedling at a point 6 feet from the naturally established pine, but on line with previous planted seedlings; (c) plant no seedlings directly under the crowns of larger established pines; and (d) plant no seedlings directly under the crowns of undesirable hardwoods more than 15 feet high or 4 inches d.b.h. unless the hardwoods are to be girdled or removed.

In machine planting on relatively level ground, the rows should be made as straight as the presence and visibility of obstacles permit, both to keep spacing uniform and to minimize crushing of the seedlings by the packing wheels when the planting machine changes direction abruptly. On rolling or hilly ground, rows should follow the contour, approximately, to prevent soil wash (Hopkins, 1949) (___). The tractor operator maintains the correct direction and spacing of rows by eye. The planter riding the machine usually depends on a sense of rhythm for correct spacing within the row, and except on rough ground a skillful man usually can set seedlings at least as regularly as a man on foot. Unlike the hand planter, however, he cannot skip places for established seedlings, since the machine prevents his seeing them in time.

Demonstration plantations, to catch the public eye and emphasize the desirability of planting, must not only survive and grow well and produce an economically attractive yield, but also "look like plantations" without the help of explanatory signs. Rows must therefore be distinct in at least one direction, preferably at right angles to a road, and should be distinct in two. Such plantations are most conveniently spaced by means of wires or light chains, marked at proper spacing intervals with paint or bright rags; ropes are less desirable because they may shrink or stretch during planting.

Accurate spacing pays in experimental plantations because it permits finding the seedlings readily at reexamination time by

measuring from stakes at the ends of rows, or from adjacent trees, and makes unnecessary the expensive staking of every tree. This is particularly true of longleaf planted in heavy grass. It has been found easiest and most economical to lay out plot boundaries with compass and steel tape, setting stakes opposite each other on two sides of each plot to mark both ends of each row of trees (Wakeley and Chapman, 1937)(___). The trees are then planted at bright paint marks at proper intervals on a cord stretched tightly between the two stakes marking each row. No trees are planted on the boundary, however, lest they later hide the corner posts.

PLANTING AMONG PINES OR HARDWOODS

Except for planting on severely eroded sites, interplanting and underplanting are perhaps the most difficult and expensive operations the planter of southern pines has to face. Yet these means of bringing ragged natural stands [41] of pine seedlings or

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41/ Replanting or replacement planting to bring plantations with poor initial survival back to full stocking is discussed on pp. 405 to 411.

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saplings to full stocking and of converting low-value hardwood stands to pine are technically and economically feasible over large areas in many forest types.

Immense amounts of inter- and underplanting need to be done. The data summarized in table 1 (p. 2) suggest that 40 percent of the area most likely to be planted in the southern pine region will require one or the other of these procedures in some degree, and that on 30 percent, or about 4 million acres, the work is likely to involve complex technical problems. Later data indicate more than 1.7 million acres of scrub oak in need of planting in Florida alone (McCormack, 1949; McCormack, 1949; McCormack, 1950)(___, ___, ___). Ross, from a study in Randolph County, Alabama, concludes that the need for stand conversion is particularly urgent on many farms if farm woodlands are to yield the financial returns they should (Ross, 1943)(___). Other studies in Alabama have substantiated Ross' findings by showing that, on an average for four largely agricultural Alabama counties, pine was failing to reproduce in half the woodlands for lack of seed source and in a quarter of them because of competing hardwoods or of hardwoods and scanty seed source combined (Brinkman and Swarthout, 1942)(___). Closely similar conditions exist in much of the Piedmont (Barrett and Downs, J.A.R., 1943) (___) and in parts of the Coastal Plain (fig. 36) from Maryland to Texas.

F465229

Figure 36.--Scrub oak stand (left) requiring conversion by planting to make the site as productive as that in properly managed natural longleaf pine (right). Both areas were logged in the same operation 25 years previously. Bogalusa, Louisiana.

Planters in the South, as in the Lake States, have hitherto tended to plant the easy, open areas first, and, where they have underplanted brush, have too often made the erroneous assumption that "the overstory would protect the planted trees during early life, and then obligingly open up at the proper time and allow them to pass

through and grow unmolested" (Rudolf, 1937)(___). As a result, less explicit information is available than one might desire concerning interplanting, underplanting, and effective stand conversion in the southern pine region.

Planting Among Pines

Especially in the longleaf type, but in many areas of other types also (Minckler, 685, 1941)(___), there are hundreds of thousands of acres with no seed source immediately in sight, with too few seedlings to make an operable stand, and with such large openings among established seedlings or saplings that many trees can be planted without fear of competition from established pines. Since seedlings planted in the openings will normally reach pulpwood size before the widely separated seedlings already established produce much seed, planting will gain at least a pulpwood rotation on whatever percentage of the area is now in openings (Coulter, 1946) (___). Although precise evidence is lacking concerning the maximum degree of stocking it pays to increase by planting, and the minimum size of opening in which planted trees can escape serious competition from pines already established, the U. S. Forest Service standards for plantable areas and for planting next to established seedlings (pp. 317 and 358) may be helpful guides on these points.

The earlier in the life of the established seedlings and saplings such interplanting is done, the greater is the likelihood that the planted trees will escape serious competition, and the greater the financial returns are likely to be. Planted pines seem to survive less well next to pine saplings than next to oaks of the same size, particularly on sandy soils. This has been shown by slash pine planted among scattered longleaf 2 to 4 inches in diameter on light soils in Alabama. Openings in understocked old-field shortleaf pine stands apparently repay interplanting with shortleaf only if they are at least twice as wide as the height of the established trees among which they occur (Minckler, Ecol. Monog., 1946)(___).

Interplanting one species with another may be advantageous for the insurance offered by mixed stands (pp.18 to 23). Slash pine (and, on sites favorable to it, loblolly pine) interplanted among young natural longleaf just starting height growth, has a better chance of keeping up with the natural seedlings than planted longleaf would have. Planted slash and loblolly may similarly keep pace with young natural shortleaf. In northeastern Florida (Coulter, 1946) (___) and even in the face of severe rust hazard at Bogalusa, Louisiana, slash pine has been interplanted extensively in young, understocked, natural longleaf stands to insure an earlier yield of pulpwood and a well distributed source of slash pine seed for future natural reproduction.

Pruning established trees during or after the interplanting of a sparse natural stand may appreciably increase the value of the products obtained from them (p.420). Pruning the established trees severely enough to check their growth somewhat (p. 421) has been suggested as a means of improving the survival, growth, and form of the planted trees, but its effectiveness with southern pines remains to be demonstrated.

Planting Among Hardwoods

The conversion of low-valued hardwood stands by planting pines may be accomplished in several ways, dependent upon the character of hardwood stands. Where hardwood brush is open and offers little competition to the planted pines, planting can be straight through and release from the hardwoods may never be needed. Dense brush requires some form of broadcast control treatment, usually best applied before planting. Open stands of large-size hardwoods may be fairly well converted by planting only in the openings and leaving the hardwoods at least temporarily untreated. Dense stands of large hardwoods ordinarily will have to be opened up prior to planting by killing or removing the hardwoods individually; if this cannot be done, the pines should be released as soon after planting as possible.

Whatever method is dictated by the condition and size of the hardwoods, the details are dependent upon the way the climate, the site, and the hardwoods themselves affect the survival and growth of the planted pines.

On dry sites with scanty or irregular rainfall, hardwoods are more likely to compete with the pines for water than for light; partial shade cast by hardwoods may be beneficial to the pines at least during the first year after planting; and sudden removal of all shade from pines that have been growing under hardwoods for several years may seriously reduce survival (DenUyl, 1948; Korstian and Coile, by Lutz, 1938; Kramer and Clark, 1947; Lane and Liming, 1939; Liming, "Response," 1946; Maissurow, 1939; Minckler, 685, 1941; Minckler, Note 61, 1946; Minckler, Ecol. Monog., 1946; Minckler and Chapman, 1948; Nelson, 1939; Rudolf, 1937; Shirley, 1945; Shirley by Baker, 1945)(___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___, ___). On moister sites, where growth of all vegetation is rank, the hardwoods may reduce survival and growth of underplanted pines mostly by cutting off the light (Kramer and Clark, 1947; Kramer and Decker, 1944)(___, ___). Hardwoods sometimes kill longleaf seedlings that have not started height growth by smothering them under fallen leaves.

The sprouting habits of the competing hardwoods materially affect the details of stand conversion. Sprouting varies greatly with climate, site, species, and age or size of hardwood, and method and season of hardwood treatment (Brasington, 1948; Buell, 1940; Buell, 1943; Bull, 1939; Bull, 1945; Liming and Seizert, 1943; Little, 1938; Smith, Lloyd F., 1947; Stahelin, 1946; Stoddard, 1937)(___, ___,

___, ___, ___, ___, ___, ___, ___, ___). As a rough general guide, less sprouting results from wide girdling and very much less results from poisoning with ammonium sulfamate than results from burning, pulling, cutting, or single girdling; hardwoods larger than about 10 inches d.b.h. generally sprout much less vigorously than smaller ones; and cutting or girdling southern oaks in summer may reduce the number and vigor of the sprouts more than does girdling at other seasons.

As a rule, all the southern pines but longleaf make increasingly greater height growth each year for perhaps the first 5 years after planting or after release, and maintain their maximum rate of growth for the next 5 or 10 years thereafter. Even longleaf does the same once vigorous height growth has begun. By contrast, the growth rate of most hardwood sprouts is greatest for the first 1 or 2 years after they start. For these reasons, planted pines tall enough to stand level with the tops of sprouts at the end of the first growing season after release, and smaller pines not too close to the sprouts, have a good chance of overtopping the sprouts. Aided by relatively long periods of height growth each year and perhaps by their ability to elaborate and store food overwinter, when all but a few species of competing hardwoods are leafless, southern pines frequently are able to grow up through light to moderately heavy overtopping hardwood stands without release. Loblolly, slash, and shortleaf seedlings severely weakened by extreme competition with hardwoods before being released, and longleaf pine under any circumstances (because of its stemless juvenile habit and natural delay in starting height growth) are least likely to overtop hardwood sprouts or untreated hardwoods successfully. (Becton, 1936; Huberman, Ecol., 1940; Liming, "Response", 1946; Mar: Moller, 1947; Minckler and Chapman, 1948; Wahlenberg, 1948)(___, ___, ___, ___, ___, ___).

Cutting hardwoods back to the ground kills part of the roots (Wood, "Sprouting," 1939)(___). Killing back the hardwood tops by burning or girdling should have the same result, and poisoning the tops is believed to be still more effective in killing roots. Even though they permit the hardwoods to sprout, these treatments therefore probably make more soil moisture as well as more light available to the planted pines.

<u>Planting in open brush</u>.--Fewer than 500 5-foot sprouts per acre or fewer than 300 5- to 15-foot hardwoods per acre are a negligible obstacle to planting. On sites occupied by such small quantities of brush, about as many pines may be planted per acre as would be planted on open land. They may be planted at regular spacing or, preferably, with some adjustment of spacing to avoid setting pine seedlings within 1 foot of hardwoods less than 5 feet high, within 3 feet of hardwoods 5 to 15 feet high, or under the crowns of larger hardwoods. Machine planting is satisfactory if the equipment is heavy

enough to get through the brush. Cutting, girdling, or poisoning of hardwoods at planting time or afterwards usually is unnecessary, especially if spacing has been modified to avoid the hardwoods.

Broadcast treatment of competing brush.--Broadcast treatments are most applicable to dense stands of slender-stemmed plants like gallberry, waxmyrtle, or blackberries, or of young oak or gum sprouts, but may be used with rank stands of palmetto and with oaks 3 to 4 inches in diameter. After treatment, planting is done at uniform spacing. Treatments include burning (p. 323); heavy furrowing (p. 324); spraying the brush with ammonium sulfamate or other herbicides; and thorough chopping of the brush with heavy rollers armed with longitudinal blades. Chopping with rollers has been highly effective in reducing gallberry and palmetto, and even scrub oak up to 4 inches in diameter (Stoddard, 1937; Williams, 1944)(___, ___). Disking in advance of planting may similarly permit successful planting of pines in dense gallberry and palmetto (Coulter, 1946)(___).

A modification of burning when scrub oaks of any size are present is to cut the oaks in August, burn the cut oaks and new sprouts in August one year later, and plant during the winter following the fire (Chapman, H.H., 1947)(___). Repeated annual fires for several winters before planting may very greatly reduce oak brush of the smaller size classes; they may do so, moreover, without eliminating all natural longleaf seedlings already partially occupying the site (Bruce, 1947; Chapman, H. H., 1936)(___, ___).

Fire is a flexible tool. A single hot fire may be used before planting to kill back fairly large hardwood sprouts on areas on which there are few or no naturally established pine seedlings. Less severe fires may be used to reduce brush, before planting, where it is desired to save established natural longleaf seedlings, or may be used to reduce brush in longleaf plantations 3, 2, or occasionally only 1 year after establishment, and even in established shortleaf stands in which the pines have reached 2 inches d.b.h. (Byram, 1948; Elliott and Pomeroy, 1948; Little, Allen, and Moore, 1948)(___, ___, ___). Burning to control hardwoods without excessively injuring intermingled pines requires, however, much judgment, skill, and care (p. 400).

Preempting openings.--On many sites occupied by hardwoods too large for broadcast treatment, the brush can be converted to operable pine stands by preempting all openings of about a hundred square feet or more (fig. 37 A) with planted pines and leaving the actual brush thickets unplanted (fig. 37 B). The method is particularly appropriate where the very size of the operation rules out such intensive treatments as girdling or poisoning individual hardwoods. Its chief disadvantage is that, because of their small size and irregular shape,

the openings must be planted by hand instead of by machine. The method is inapplicable where medium to large hardwoods occupy more than about 70 percent of the site.

F465230-31

Figure 37.--A. Sunny, grassy, unquestionably plantable opening in interior of scrub oak stand shown in fig. 36. The grass was heavy enough so that cattle had grazed it; the surrounding scrub oaks were too dense to underplant without girdling or poisoning. B. Seven loblolly and slash pines surviving out of 9 planted $5\frac{1}{2}$ years previously, at close spacing, in minimum plantable opening in 10- to 20-foot-high oak and hickory brush at Talladega, Alabama, by the Alabama Agricultural Experiment Station.

Pines planted to preempt openings in brush should always be spaced as closely as safety from stagnation permits (pp. 38 to 44). Close spacing makes full use of the growing space not encumbered with brush and helps offset the loss of production on the unplanted brushy portions. At 5.5- by 5.5- or 5- by 6-foot spacing, for example, as many trees can be planted in the openings on an acre 47 percent open and 53 percent occupied by brush as can be planted at 8- by 8-foot spacing on an acre entirely free from brush (p. 40), and plantable openings totalling only 30 percent of an acre will take more than 500 trees at 5- by 5-foot spacing.

Where most of the openings to be preempted are small, loblolly, slash, or shortleaf pines, because of their better early height growth, have a better chance of catching up to and crowding back the surrounding hardwoods than has longleaf. With this exception, species should be chosen for site as in any other planting, and on many dry sites where openings are large enough, longleaf may be the best choice.

Successful preemption of openings requires good local knowledge of how large an opening seedlings need to survive and grow well, and of how close to a wall of hardwoods pines can be planted effectively. Both these things vary widely from place to place. For example, Liming has shown that in the Missouri Ozarks planted shortleaf pine within 7 to 10 feet of unmodified oak stands may grow at only half the rate of seedlings 40 to 45 feet from the stands, and that measurable adverse effects of the hardwoods may extend outward for at least 25 or 30 feet (Liming, "Response," 1946)(___). By contrast, on an area in Alabama covered with heavy hardwood brush 10 to 20 feet high, loblolly and slash seedlings planted under the edges of hardwood crowns but receiving full light from one side, grew fast enough to overtake the hardwoods (fig. 37 B), and Wahlenberg has reported aggressive growth of natural loblolly seedlings in Arkansas in openings only 15 feet in diameter (Wahlenberg, 1948)(___). For the Central, Piedmont, and southern Appalachian regions, Minckler and Chapman

recommend confining planting to openings where direct sunlight reaches the ground (fig. 37 A) and say that if its diameter is about twice the height of the surrounding trees the opening may be planted, usually without future cutting to free the planted pines (Winckler and Chapman, 1948)(___). Through much of the longleaf type, planted seedlings of longleaf and especially of slash pine seem to survive and grow satisfactorily as close to scrub oaks as Andropogon scoparius and the commonly associated grasses are able to survive in moderate density (fig. 37 A), but, unless released, are likely to fail where the oaks have thinned out or killed the grass.

Planting should be limited to openings large enough to take 4 or more seedlings at the closest spacing acceptable for the species and site. Planting smaller openings is inefficient, and pines planted singly or in twos or threes seem to compete less successfully with surrounding hardwoods than do larger groups.

In many instances, preempting of openings will be most successful if done early. It is true that scrub oak stands open up with age, and it may be true that young vigorous hardwoods of no great height compete more severely with individual pine seedlings than do older hardwoods; data on this second point are scanty. Nevertheless, patches of hardwood are likely to become larger and openings smaller each year for many years. The hardwoods grow taller also, and become correspondingly harder for the planted pines to overtop. Therefore it may pay a planter with both brush-free and partly brushy tracts to use the former (which can be planted at any time) for grazing (Campbell and Cassady, 1947)(___) until he has finished planting the latter, or at least to plant some of both classes each year, instead of planting all his brushless areas first.

Treatment of individual competing hardwoods.--Underplanting scrub oaks and associated hardwood species with southern pines at regular spacing and cutting, girdling, or poisoning the hardwoods just before or soon after planting may often convert the hardwoods effectively to pine (fig. 38) even when the hardwoods are 20 feet high or 6 to 8 inches d.b.h. and shade 60 to 80 percent or more of the ground (Brown, 1941; Lane and Liming, 1939; Liming, "Response," 1946; Liming and Seizert, 1943; McPherson, 1940; Stahelin, 1946; Wood, 1936)(___, ___, ___, ___, ___, ___, ___). Both planted and naturally reproduced southern pines benefit clearly, in survival and especially in growth, when free of or released from hardwood competition (Abel, 1947; Bull, 1939; Bull, 1945; Smith, Lloyd F., 1947; Wahlenberg, 1948)(___, ___, ___, ___, ___). Cutting, girdling in various ways, and poisoning are applicable to practically all competing species except palmetto and such slender-stemmed species as gallberry, which in open stands require no treatment and in dense stands are most economically and effectively treated broadcast.

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Figure 38.--A. Loblolly and slash pines planted at regular spacing under dense, 10- to 20-foot-high oak and hickory brush near Talladega, Alabama, and released $3\frac{1}{2}$ growing seasons after planting and 2 seasons before picture was taken. B. Slash pine planted at regular spacing under dense 12- to 15-foot-high hardwoods at Auburn, Alabama, and released 4 years after planting and $8\frac{1}{2}$ years before picture was taken.

Effective release by cutting or girdling the hardwoods need not be prohibitively expensive. Although increases in the growth of pines planted or naturally reproduced under hardwoods generally are greater the greater the degree of release (Becton, 1936; Buell, 1943; Lane and Liming, 1939; Liming, "Response," 1946; Minckler and Chapman, 1948; Stahelin, 1946)(___, ___, ___, ___, ___, ___), it is by no means always necessary to cut or girdle all the hardwoods. Often only those hardwoods competing strongly with or actually overtopping the planted pines need be treated. McPherson treated such hardwoods on a representative brushy site at a cost of 1.7 man-hours per acre; Liming advocates reducing the basal area of overtopping hardwoods to less than 27 square feet per acre; Stahelin suggests complete release where labor is abundant, hardwood can be sold for fuel, and pine can be sold for pulpwood, but only partial release where labor is scarce and sawlogs are to be the principal pine product (Liming, "Response," 1946; McPherson, 1940; Stahelin, 1946) (___, ___, ___). Combining release of planted pines with domestic or commercial utilization of scrub oaks or other competing hardwoods is sometimes an ideal solution of the problem; it should often be possible on farms (Abel, 1947; Wood, 1936)(___, ___) and sometimes on larger holdings (Hall, 1945)(___), especially with the increased use of hardwood for pulp (Collett, 1947)(___). Planting of shortleaf pine following cutting of oaks for fuel, with subsequent cutting of sprouts, has been an established practice in New Jersey for more than 20 years (Moore, 1940)(___).

With either cutting or girdling, average cost per tree increases with diameter of tree (Clark and Williston, 1948)(___). Double-hack girdling (cutting into the sapwood and prying out the chips in a ring 3 inches wide) is most effective in killing hardwood tops and may reduce sprouting, but is considerably more expensive than single-hack or frill girdling. Special girdling tools (Cuno, 1936; Cuno, 1937; Heimburger, 1937; Liming, 1941)(___, ___, ___, ___) may be more efficient than axes under some circumstances. Unless the pines to be released are very small, girdling usually is done knee-to waist-high to save expense. As a rule, it is most economical to cut hardwoods less than 4 inches in diameter and to girdle those 4 inches in diameter and larger. The lingering shade cast by girdled trees does no harm and may reduce mortality from too sudden exposure of the pines, and damage to pines from falling tops of girdled hardwoods is negligible (Bull, 1939; Liming, "Response," 1946)(___, ___).

The time at which competing hardwoods are cut or girdled often materially affects the success of stand conversion. Often the main difficulty in releasing planted southern pines is the impossibility of deciding whether cutting or girdling the hardwoods at any given time will actually let the pines outgrow the inevitable sprouts.

Underplanted slash and loblolly pines have responded to release by cutting or girdling the hardwoods from 2 to 3 or 4 years after planting, but have not always benefited from such release at time of planting. Shortleaf may repay release any time up to 10 years, but Liming recommends release at time of planting. Investigators of underplanting, stand conversion, and related problems near the borders of the southern pine region (Becton, 1936; Buell, 1943; Chapman, A. G., 1944; Lane and Liming, 1939; Liming, 1945; Liming, "Response," 1946; Liming and Seizert, 1943; Moore, 1940; Nelson, 1939; Wood, 1936)(___, ___, ___, ___, ___, ___, ___, ___, ___, ___) have in general recommended earlier release than have those in the interior portions of the region (Abel, 1947; Brown, 1941; Bull, 1939; Bull, 1945; Korstian and Coile, by Lutz, 1938; McPherson, 1940; Smith, Lloyd F., 1947; Stahelin, 1946)(___, ___, ___, ___, ___, ___, ___, ___).

Correct timing of cutting and girdling to release planted longleaf pine is particularly difficult. If the hardwoods are cut or girdled before the longleaf has started active height growth, their sprouts are almost sure to overtop the longleaf; yet without treatment of the hardwoods the longleaf may never start, or even survive (Stahelin, 1946)(___).

The simplest and surest way out of the time-of-release difficulty is to poison the hardwoods. Although poisoning may not kill all competing hardwoods and prevent all sprouting, it should, if correctly done, reduce both original hardwoods and new sprouts sufficiently to give the pines, including even longleaf, a permanent advantage, and to make the exact year of treatment less important than in the case of cutting or girdling. There is increasing evidence, however, that poisoning the hardwoods just before or immediately after planting is most beneficial to the pines.

Ammonium sulfamate (trade name Ammate) and sodium arsenite have been found highly effective for poisoning competing hardwoods in the southern pine region, but sodium arsenite is too dangerous to both men and animals (including livestock and deer) to be recommended. Ammonium sulfamate is not poisonous to animals and is harmless to handle unless left in contact with the skin for a long time; it is, however, very corrosive to metals. The somewhat higher costs of poisoning competing hardwoods by applying ammonium sulfamate in cups or frills or on notched stumps, or sometimes as a foliage spray, as compared with those for cutting or girdling, appear to be more than

balanced by the better results. Ammonium sulfamate has been applied commercially by these methods over many thousands of acres. Latest directions for applying it and other promising hardwood poisons may be obtained from the Southern Forest Experiment Station. (Anonymous, "Weed trees," 1947; Brasington, 1948; Cassady and Peevy, 1948; Cook, 1944; MacKinney and Korstian, 1932; New York State College of Agriculture, Department of Forestry, undated; Peevy, 1946; Peevy, 1947; Peevy, 1949; Pessin, 1942)(___, ___, ___, ___, ___, ___, ___, ___, ___, ___).

PLANTING COSTS, RATES, AND RECORDS

The most comprehensive figures available on the combined costs of preparing sites and transporting and planting southern pine seedlings are those of the U. S. Forest Service for the period 1937-38 through 1941-42. These show planting costs (averaged for groups of ranger districts or of national forests) ranging from $1.06 to $11.49 per thousand trees, or 45 to 55 percent of total seed, nursery, and planting costs (table 5). Planting costs per thousand trees for individual Forest Service planting sites, such as might match individual farm or small industrial planting jobs, varied much more widely than these averages for groups of sites. Although the Forest Service planted at 6- by 6-foot spacing (1,210 trees per acre), the presence of some established seedlings and unplantable brush reduced costs per acre almost to those per thousand trees.

Smith published what are believed to be the earliest reasonably complete cost accounts for large-scale commercial planting of southern pine (Smith, B. F., 1932)(___). He reported the average cost of planting on 5,200 acres of cut-over longleaf pine land in southwestern Louisiana during 1925-26 through 1930-31, mostly with slash and loblolly seedlings, as $1.60 per acre, or 43 percent of the total for seed, nursery, and planting combined. All planting was by hand, with bars. Most or all of it was at 6- by 8-foot spacing (about 900 trees per acre) in plowed furrows.

Comprehensive data are not yet available for large-scale hand planting at post-war wages, or for machine planting. It seems reasonable to assume, however, that hand planting which cost the U. S. Forest Service an average of $2.43 to $4.87 per thousand trees during the CCC program might cost $5 to $10 per thousand at post-war wages. Cost figures available on machine planting range from $2.19 to $4.08 per thousand trees on old fields and from $3.87 to $8.33 per thousand on cut-over land, and are reported to be from less than half to about three-quarters of the cost of hand planting on comparable sites (Davis, J. E., 1947; Hardee, 1948; Hopkins, 1949; Smith, McClain B., 1949)(___, ___, ___, ___).

In erosion-control planting and in planting among established pines or hardwoods, higher costs than those quoted for cut-over longleaf land can scarcely be avoided.

Prewar ball planting of wildlings with the Council special seedling lifter and transplanter cost $9.00 to $16.57 per thousand trees, depending largely on the distance the seedlings had to be transported and on the skill and experience of the crews (Morriss, 1940) (___) (State Forester C. H. Coulter of Florida, personal communication).

Even when sites, planting methods, spacing, and wages are comparable, costs of planting, like seed costs and nursery costs, vary so much from place to place and from year to year that average costs of past operations can serve as only very general guides in planning new work. Failure to allow for differences in site, methods, spacing, or wages may make planting costs recorded on one job seriously misleading in estimating costs for another.

Rates of Planting

Rates of planting, in terms of trees per man-day or man-hour, are more useful than planting costs in planning new operations or judging efficiency. While rates vary with the training and organization of the crew, they are independent of wages paid and (except in extreme cases) of the spacing used, and are related rather directly to the difficulty of planting particular sites and to the methods used. While no comprehensive data on rates are available, the following are among the more reliable examples.

During the 1920's 100 trees per man-hour, exclusive of the time of foremen and tree carriers, was considered the ordinary minimum rate for men working in pairs and planting good stock on open cut-over longleaf pine land. The rate was exceeded by the best planters in early commercial planting when soil, weather, and the sizes of seedlings all were favorable, but was not maintained on very wet or heavy soil, in brush, in cold or rainy weather, or with very small seedlings (Wakeley, 1935)(___). Farm planting was probably slower as a rule, even on favorable sites.

On the national forests during the CCC program, output was considerably improved by having the bar-man carry and set his own trees, and by rigorously training all planters in correct use of the bar (pp. 567 to 569). Under normal working conditions rates as low as 100 trees per man-hour were rare on cut-over longleaf pine land; rates of 120 to 140 trees per man-hour were common even where some brush and some heavy soil was encountered; a few of the best squads on the easiest sites averaged 270 to 300 trees per man-hour throughout the planting season (unpublished data, U. S. Forest Service). These figures are output per man-hour, in terms of averages for all men in the planting squad, including 1 non-planting leader and 1 or 2 non-planting tree carriers to each 15 to 17 bar-men. The usually high survival of the trees planted by the fastest crews is attributed to the fact that only by nearly perfect planting can planters avoid fatigue and maintain maximum speed.

Coulter reports 500 to 700 nursery seedlings bar-planted per man-day (63 to 88 per man-hour) in farm and commercial planting in Florida (Coulter, 1946)(___). These rates probably are conservative for many Florida conditions.

Minckler and Chapman give the following approximate rates (in trees per man-hour) for planting under various conditions in the Central, Piedmont, and Southern Appalachian regions (Minckler and Chapman, 1948)(___):

Rough, rocky land, mattock-hole planting	38
Smooth land, bar or mattock-slit planting	75
Smooth land, bar or mattock-slit planting in furrows	100

The rates for mattock-hole and mattock-slit planting are slightly below others reported for the Central States (Kroodsma, 1939)(___).

Planting machines, operated by either two or three men including the tractor driver, are variously reported to plant 938 to 1,750 trees per machine hour, with seasonal averages near the lower figure (Anonymous, Tree Planters, 1947; Davis, J. E., 1947; Hardee, 1948; Hopkins, 1949; Smith, McClain B., 1949)(___, ___, ___, ___, ___).

Wildings transported from 300 yards (in wheelbarrows) to as much as $1\frac{1}{2}$ to 3 miles (in wagons or trucks) have been lifted and planted with the Council special seedling lifter and transplanter at rates of 184 to 500 trees per man-day (Coulter, 1946; Swarthout, 1941)(___, ___).

Records

Minimum plantation records should include location, boundaries, area, date of establishment, species, and geographic source of seed. It is also desirable to include the arrangement and spacing of trees; the average number planted per acre; the class, age, and grade of nursery stock; the exact method of planting used; any insects or diseases carried into the plantation on stock; any dip or spray used at lifting or planting time; and the condition of the site at time of planting, together with any hazard present and control measures used. After establishment, desirable records are: locations and dates of pest outbreaks, with mortality percent and nature and effects of control measures; and locations, dates, nature, and results of releases, thinnings, and prunings. Less often needed are records of survival, growth, and yield by periods.